Chemical Preservatives in Wood Protection 16

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Abstract

Wood is an essential renewable resource which has been utilized in most of the sectors like housing, construction, furniture making, etc. Due to the immense damage caused by the wood degrading agents, there is a surge in demand to protect wood and its products. Wood preservation is an impeccable step to elude the degrading agents. It prolongs the service life of wood and its products. Numerous treatment methodologies have been inculcated for applying the preservatives in wood. As a result, the treated wood improves resistance against the agents of degradation. The preservatives used should be economical and less hazardous to living beings and environment. The main objective of this chapter is to convey to researchers about the recent developments on chemical preservative formulations which have an immense efficiency in enhancing the service life of wood and its products than the ones used earlier.

Keywords

Wood preservation · Chemical preservatives · Wood degrading agents · Service life

16.1 Introduction

Wood plays a vital role in the world economy, due to its abundance in nature and versatility. Wood is extensively used in sectors like construction, furniture making, housing and so on. It will remain as a leading building material until and unless there is an adequate amount of supply at a reasonable cost. Because of its organic nature, wood is susceptible to degradation. There is an increase in demand for preserving wood and its products from biodegradation. Wood preservation implies the safety of wood against any factor which creates irreversible damage and eventually destroys wood. However, wood preservation in an applied sense refers to the enhancement of wood’s natural durability by treating it with chemicals that are lethal to insects, fungi and other decaying agents. The prime objective of the preservative treatment of wood is to intensify the service life of wood, thus increasing the ultimate cost of the product and evading the need for frequent replacements. Use of toxic metal complexes as wood preservatives has brought interest in employing natural and eco-friendly preservatives. The existing advancement and employment of novel technologies has been restricted due to unpredictability in terms of the outcome amongst the laboratory and the field routines of natural products substitutes, and legal glitches derived from the absence of globally defined quality standards. Extractives from plants, biological control agents, and combination of chemical and natural procedures are evolving as fractional solutions to regulate wood deteriorating creatures such as fungi and termites (Groenou et al., 1952). Systematic approach has to be made in order to protect wood, starting with moisture content because the deteriorators require water source to deteriorate the wood. Finishes, comprising water repellents, can aid to safeguard wood in insignificant deterioration environments, as above-ground conditions (Loferski, 1999). There are numerous advancements made with respect to the assessment of organic and inorganic biocides for the improvement of viable method to be applied for preservatives. Imperative methodologies for protecting the wood have been employed and also negotiable amount of impact on environment by the preservative formulation is acknowledged. It is anticipated that at some stage, the totally organic systems will be mandatory for wood products in residential uses (Laredo, 1996).

The process of penetrating or incorporating the preservatives into the wood at a depth using traditional methodologies which in turn will provide effective, long-term resistance against the fungi, insects and marine borers is said to be termed as wood preservation. Wood preservation was initially introduced as an industrial process and it is constantly being in use where there is decay is evident and unavoidable (George et al., 1953). For example, decay caused by fungi is completely dependent on the presence of moisture, hence there should be a consideration made on inventing a protocol to maintain the wood from fungal attack, irrespective of wood species. Preservative treatment method should be designed in such a way that there shouldn't be any probabilities of replacing the wood and the protocols must be accurate, justified and of less cost, thus conserving our forest. Wood importing countries will desire to decrease wood import as to lessen currency while the wood exporting countries will implement preservation in order to reduce home demand for replacement wood, thus leaving the extreme volume available for export (Swiderski, 1967). By prolonging the service life of timber, wood preservation diminishes the harvest of valuable forestry resources, eases functioning costs in industries such as utility and railroads, and guarantees harmless conditions where timbers are utilized as support structures. Moreover, to industrial and commercial application, a substantial portion of the treated wood volume is used for residential construction to guard homeowner's funds and offer outdoor living spaces that are a preferred part of living. The practice of utilizing preservative chemicals and treated wood has been and still is occasionally criticized on the basis of health or environmental concerns. Unawareness on the part of the treating industry, poor work practices and lax environmental regulation, all share part of the blame for that negative perception. Innovation in the first half of the twentieth century led to the development of more effective wood protecting chemicals and processing techniques that turned a speciality industry into a commodity business. As can happen in all commodity businesses, research and development was not continuous when profit margins began to collapse and the door was opened for competitive products such as plastics, concrete and steel (Bowyer et al., 2007).

16.2 Wood Degrading Agents

Wood products can be attacked by a variety of biodeteriogens such as fungi, insects and bacteria, depending on where they are used. Fortunately, wood can be protected from biodegradation in a number of ways. The ideal choice depends on the local environment and the organisms present.

16.2.1 Decay

It is the highest destructive form of fungal attack on wood. It is prominently found in three forms, namely brown, white and soft rots. The terminology relates to the physical appearance of the wood after it has been extensively attacked. Brown and white rots result from the growth of highly specialized higher fungi (Basidiomycotina). The hyphae of Basisdiomycetes are able to ramify through the three-dimensional structure of wood creating large bore holes in the cell walls. These fungi utilize extracellular enzymes to degrade the wood cell walls to derive their nourishment. Under optimal conditions the process quickly weakens infected areas. Soft rot is caused by another group of higher fungi (Ascomycotina and Deuteromycotina) which produce fine bore holes without the extensive enlargement seen with the Basidiomycetes (Clausen & Yang, 2007).

Brown rots are usually allied with softwoods. The fungi attack mainly the cell walls carbohydrates (cellulose and hemicelluloses) and change the structure of lignin only slightly. As a consequence, the decayed wood develops a brown colour that will eventually exhibit extensive cracking as it dries. The fungi can wet wood by transferring water over considerable distances along macroscopic root-like structures formed by aggregations of hyphae. White rot affects both softwoods and hardwoods. Cellulose, hemicelluloses and lignin are degraded. Progressive erosion by hyphae in the cell lumen as well as bore holes weakens the cell walls. Wood affected by white rot may darken in the early stages of decay but as the decay advances bleaching may occur. It does not split into fragments but, because the breakdown of the lignin weakens inter-fibre bonding, the wood becomes stringy in texture. Soft rot is a form of decay caused by a quite different group of fungi which are closely related to moulds. They usually attack wood in wet conditions than those favoured by brown and white rot fungi. Soft rot fungi characteristically attack the surface of the wood, gradually eroding inward at the rate of a few millimetres per year (Andersen & Elborne, 1999).

16.2.2 Insects and Termites

Wood destroying insects are of major significance in most regions of the world, although the number of species involved is relatively small. They damage wood by chewing it with their mandibles, although in many cases they derive no direct nourishment from it. From a wood durability perspective, insect attack is less predictable than decay because some insects can bore into sound dry wood, and because insect populations are not uniformly distributed. However, most insects are similar to fungi in attacking only moist wood. In the natural environment most wood decomposes as a result of both insect and microbial activity. Most insect pests of wood are either termites or beetles. Other insects such as wood wasps, moths, carpenter bees, etc. are significant locally (Creffield, 1996).

All termites feed on cellulosic materials. The most important are the subterranean termites that are found throughout the world within 40° to 45° of the equators. The number of species and total termite biomass increases nearer the equator, and they are generally regarded as a more serious threat in tropical and subtropical regions. Like all Isoptera, subterranean termites are social insects that live in colonies that are established in the soil. In their quest for food, subterranean termites may enter buildings and other above-ground structures through enclosed galleries which they construct to protect themselves from desiccation and which connect to the soil and ultimately to the colony. Traditionally wooden structures have been protected by treating the soil under and around the building with an insecticide, subsequent soil treatments are necessary to maintain protection. Physical barriers such as metal caps between building and foundation supports have some limited value in that they force the colony to construct an enclosed gallery across both faces of the cap and thereby warn the homeowner of their presence. Soil barriers such as graded gravel and steel mesh show some promise, as do toxic bait systems. The bait systems use slow-acting insecticides, allowing foraging termites to return to the nest to feed the colony. Building with preservative-treated wood provides another layer of protection if other protection mechanisms fail. The best control is achieved by using preservative-treated wood (Su & Scheffrahn, 1993).

16.3 Necessity of Wood Preservatives

There are certain species of wood which are durable naturally. Resistance against fungi and insects can be exhibited by the heartwood of trees to certain extent. This natural durability can be attributed to amalgamate lethal extractives existing in the wood and low innate penetrability. As a result of this natural durability such woods can be used outdoors and in some cases in ground contact or submersed in water. Wood from naturally durable species is sometimes observed as being environmentally desirable to chemically treated wood, and many of these species have an eye-catching appearance. In addition, some species such as black locust, greenheart has exceptional strength assets. As might be predictable such a blend of desirable attributes has directed to increasing attention in use of durable species from the tropical countries for construction in European countries. Nevertheless, numerous aspects limit the use of naturally durable species. In developed countries the capacity of mounting stock of naturally durable species is comparatively low related to the demand for durable wood products. In view of the limited supply of natural durable wood species, it is valuable to supply less durable wood treated with preservatives. Preservative treatment of wood therefore is significant to protect the wood resources. Wood preservatives are chemical constituents that when appropriately applied to wood, makes it resistant to fungi, insect and woodborer (Bowyer et al., 2007). There are two universal classes of wood preservatives: oils, such as creosote and petroleum solutions of pentachlorophenol; and waterborne salts that are applied as water solutions. The efficiency of the preservatives diverges momentously and can depend not only upon its composition, but also upon the quantity injected into the wood, the depth of penetration, and the conditions to which the treated material is exposed.

The choice of wood preservatives depends upon the character of the wood to be treated, the anticipated service life and the properties of the chemical or formulation. Wood preservation formulations must

- Be toxic to fungi, termites, borers and marine organisms.
- Be free from objectionable properties in use and handling.
- Be chemically stable.
- Be safe to handle.
- Not have corrosive properties.
- Not be expensive.
- The permanency of the wood preservative in the treated wood during various uses such as resistance to:
- Leaching by water.
- Rapid evaporation due to heat.
- Chemical conversion affected by oxidation, reduction and polymerization.
- Chemical or enzymatic action causing a dropping of toxicity level.
- The inflammability of treated wood should not intensify by the preservative.
- Ease of transportation over long distances in wood.

16.4 Types of Wood Preservatives

There are four main types of preservatives, viz., oil type, organic solvent type, non-fixed water-soluble type and fixed water-soluble type (Table 16.1).

16.4.1 Oil Type Preservatives

There are various oil type preservatives like creosote and coal tar creosote. The tar produces a brownish-black oily liquid obtained after the process of distillation or carbonization of bituminous coal. It can also be said as the distillate fractions of coal tar which boils at a temperature between 200 and 400 °C. It is an amalgamation of

Table 16.1 Preservative formulations over the years

Chemical complexes		Metallic complexes	
Chemical	Year	Chemical	Year
Creofixol	1919	Mercuric chloride	1705
Creosote oil + coal tar + petroleum	1920	Aczol	1907
Copper sulphate	1938	Boliden salt	1932
		Chromate zinc chloride	1934
		Zinc sulphate	1945
		Fluorine	Nineteenth century

complex organic compounds. The comparative amounts of it barely rely on the composition of the original coal tar and the process by which it was carbonized. Its advantages are high toxicity to wood destroying microbes, relative insolubility in water and low volatility, which impart to it a great degree of permanence under the most varied use conditions, ease of application, ease with which its depth of penetration can be evaluated, general obtainability and relative cost and long record of satisfactory use. Oil type preservatives comprise of vigorous chemicals, an insecticide or a fungicide, dissolved in an organic solvent, such as a petroleum distillate. Of the millions of organic chemicals, only less than ten can be used as active ingredients in the formulations. Application of these chemicals provides lifelong protection due to their natural insolubility in water. After evaporation of the organic solvent the active chemicals persist in the wood (Jun & Wenjin, 2009).

16.4.1.1 Creosote

Initially, the oil produced from the wood was termed as creosote. It has been recorded that coal tar creosote was the traditional wood preservative used enormously for more than fifteen decades. The oily liquid produced during the carbonization of bituminous coal is said to be creosote. This has a complex chemical composition which gets formed when it is boiled at an extremely high temperature of about 200 to 400 °C. It possesses numerous compounds such as hydrocarbons, tar acids and bases. It has an immense capability of preserving wood and its products and is hydrophobic in nature. As a result, resistant to leaching, noncorrosive to metals, and has a high electrical resistance; it protects timber against splitting and weathering (Gabriele, 2004). Creosote is usually applied by an empty-cell process and occasionally by hot-and-cold open tank process. These are actually very harmful to plants because of its strong odour and volatility. Hence creosoted timber isn't preferred to use in food containers. At certain times, other chemical complexes are bombarded with it in order to fortify by increasing its performance. The addition of 2% pentachlorophenol eradicates the decomposing of creosoted posts in the ground by *Lentinuslepideus*. Copper comprising preservatives are added in contradiction with the marine borer, *Limnoriatripunctata*. Insignificant quantities of arsenic trioxide are added to develop the preservative properties against termite attack. Creosote loading is 400 kg/m^3 in full-cell process and 140 kg/m^3 in empty-cell process (Jacoby & Freeman, 2008).

16.4.1.2 Lindane and Dieldrin

In the early nineteenth century, Lindane was discovered and was in use till 1940's as an effective insecticide which was not accumulating in the environment. It was used as a spray or dipping treatment of hardwood logs against *Lyctus* beetles in joinery treatments by immersion or double vacuum processes, and in situ remedial treatments against insect attack in buildings. Dieldrin was introduced in the year 1948 and is also being used as insecticide which is persistent in the environment. These are stable chemically, insoluble in water and is extremely toxic to insects. Dieldrin is applied in joinery treatments for protection against termites and also used mainly as water-based dispersion for soil pretreatments against termites. It is used as 0.8% solution in petroleum solvent (Morrell & Levien, 2000).

16.4.1.3 Copper 8-Quinolinolate

Copper 8-quinolinolate known as Copper-8 is a relatively new preservative. It is manufactured by condensation of copper 8-quinolinolate and nickel 2-ethyl hexoate. Copper-8 is yellow-brown solid and made soluble in organic solvents by nickel 2-ethyl hexoate to give a green solution. It is toxic to wood pests except termites, but relatively harmless to animals and plants. This preservative is applied in wood material used for food containers, refrigerators, seed boxes and greenhouse. Treatment solution should contain 0.045% Cu (Morrell & Levien, 2000).

16.4.1.4 Copper Naphthenate

The preservative used first in 1920s as 'Cuprinol' gives dark-green waxy solution in organic solvents and waxy solution in organic solvents and waxy wood surface prevents over-painting. It is toxic to wood pests except termites and non-corrosive to iron or steel. Copper naphthenate is mainly used as paint-on preservative for boat maintenance. Treatment solutions contain 1 to 2% Cu (Gjovik et al., 1981).

16.4.1.5 Bis (Tri-N-Butil Tin) Oxide

It is known as tributyl tin oxide, TnBTO, or TBTO, excellent fungicide, more effective than PCP, insoluble in water, soluble in many organic solvents. TBTO has lower toxicity to humans than PCP. This preservative is mainly used as fungicide in joinery treatments and as a general preservative for boat maintenance. TBTO is applied as 0.5 to 1.0% solutions (Brooks, 2000).

16.4.2 Organic Solvent Type

Organic solvent-based preservatives are different from the creosote. These are chemically active and are enormously efficient as fungicides and insecticides. Before applying the preservatives onto any surface of the wood, it should be dissolved in organic solvents (Dobbs & Grant, 1978). About two dozen of complexes were found as preservatives. It was especially used for the joinery timbers as water repellent. In addition to this wax and resins can also be used as water repellents. This shows a significantly higher degree of penetrability. It can also be applied under low vacuum or dipping. The most common organic solvent type preservatives are pentachlorophenol (PCP), benzene hexa-chloride (BHC), dichloride-diphenyl-trichloroethane (DDT), synthetic pyrethroids, metallic soaps, precipitated soaps and fused soaps.

16.4.2.1 Pentachlorophenol

Pentachlorophenol known as Penta or PCP is the utmost vital and extensively used fungicide of organic solvent preservatives. Commercial product manufactured by direct chlorination of phenol comprises about 85% PCP. It is extremely toxic to fungi, insoluble in water and resists leaching, non-volatile and non-corrosive to metals. Five percent solution of PCP in heavy oils is used in the treatments (Zarus, 2004). It has very low solubility in water and low volatility and is a very stable chemical, therefore it is the most promising and widely used preservative of oil borne chemical type (Matsunaga et al., 2009). It has been found ineffective against marine borers and never used for the protection of wood in salt water.

16.4.2.2 Synthetic Pyrethroids

The discovery of synthetic pyrethroids was done by the Rothamsted Experimental Station and was found it as an acceptable alternative for the chlorinated hydrocarbons. These are persistent and highly stable at the site of application, yet can be biodegraded and do not accumulate in the vertebrate body. They are having diverse acute mammalian toxicity; those with high mammalian toxicity were decamethrin. This indeed has remarkable insecticidal effectiveness which is usable at working concentrations and also considered as a safety standpoint. It is clear that synthetic pyrethroids are of great interest as potential wood preservative insecticides (Elliot et al., 1973).

16.4.3 Non-fixed Water-Soluble Type

Waterborne preservatives will let the surface of the wood relatively clean, paintable and devoid of objectionable odour. Among the water-soluble non-fixed wood preservatives are borax, boric acid, sodium pentachlorophenate, copper sulphate, mercuric chloride, and sodium fluoride and zinc sulphate. Although they are highly effective against fungi and insects, boron preservatives are not fixed; hence wood treated with boron salts cannot be used in contact with the ground or in wet conditions. These preservatives may further be categorized as.

16.4.3.1 Leaching Type

These are the salts (organic and inorganic) which are soluble in water (Mantanis et al., 2014). It is only used for the application on timber than on any others. They easily get leached when it is constantly exposed to rain water. Few preservatives which come under this category are:

- *Zinc chloride*: It is fairly lethal to fungal microorganisms and insects. But it is not an effective chemical complex to eradicate termites. It is hygroscopic in nature and also has fire-retardant properties.
- *Boric acid and Borax*: These are extremely toxic to almost all kinds of organisms which are encountered with timber. It has a very good penetrating property making it a very good preservative for wood and its products.
- *Sodium pentachlorophenate*: The water-soluble sodium salt of pentachlorophenol is enormously effective against the sap stain.

16.4.4 Fixed Water-Soluble Type

The fixed water-soluble type intended mainly for external use contains salts that service to fix the preservative chemicals in the wood and render them non-leachable. The most prolonged and effective protection has been achieved by the use of carefully balanced mixtures of copper, chromium and arsenic salts. These are the mixtures of various water-soluble salts with the addition of a fixative salt, usually sodium or potassium dichromate. Once the timber is treated it should be allowed to dry for 3 to 6 weeks of time for a complete fixation. These are used in impregnation of mine props, domestic buildings, food containers and cooling towers. It is preferred for structural elements which are not to be painted and do not have any odour. Concentration of the solutions is about 5%. Few preservatives which come under this category are copper chrome arsenic (CCA), acid cupric chrome composition (ACC), chromated zinc chloride (CZC) and copper chrome boron (CCB).

16.4.4.1 Ammoniacal Copper Arsenate (ACA)

It is known under the trade name of chemonite with the composition of copper hydroxide (Cu $[OH]_2$), arsenic trioxide (As_2O_3) and ammonia (NH_3). In the USA, it is a very well-known wood preservative and is also used to treat refractory softwoods. A slightly modified composition using ammonium hydroxide and arsenic trioxide was developed to treat timber by the Dip diffusion method. The preservative has given good indications of its use in the rural sector and treatment of wooden panels. Service records on chemonite-treated wood show that the preservative provides good protection against fungal decay and termites.

16.4.4.2 Acid Copper Chromate (ACC)

This product known as Celcure consisted of copper sulphate ($CuSO_4.5H_2O$), sodium dichromate ($Na_2Cr_2O_7$) and chromic acetate ($[Cr_2H_3O_3]\ H_2O$). Wood products which are well impregnated with the Celcure have potential anti-termite activity. It shows a commendable resistance against marine borers too.

16.4.4.3 Copper Chrome Arsenic (CCA)

It was initially developed by Kamesam (1933) as a preservative which comprises hexavalent chromium, copper and inorganic arsenic or [$CuSO_4.5H_2O$ (3%) + $Na_2Cr_2O_7/K_2Cr_2O_7$ (4%) + $As_2O_5.2H_2O$ (1%)]. During 1940s, in CCA, copper is the primary fungicide, arsenic is a secondary fungicide and insecticide and chromium is a fixative. CCA is a preservative that was extremely common for many decades as it is having high solubility in water and also it was used to pressure treat lumbers. In the 1970s, it was widely used for residential wood such as picnic tables, decks, fencing, landscaping timbers, etc. Environmental impacts on the use arsenic are of concern as this chemical may leach from the wood into surroundings and soil resulting in toxicity to bio-organisms. Excessive use of arsenic-based preservative is posing serious problems to the environment. Kenneth (2000) reviewed the environmental impacts of arsenic. Long (1997) reviewed the arsenic leaching from pressure-treated wood. Environmental Protection Agency (EPA) and US Consumer Products Safety Commission (USCPSC) assessed the toxicity of arsenic. In 2003, the EPA phased out CCA as it had the potential to cause irreversible damage to human beings.

16.4.4.4 Copper Chrome Boric Composition (CCB)

This was also developed by Kamesam in 1943. It has a chemical composition of copper sulphate ($CuSO_4.5H_2O$), boric acid (H_3BO_3), potassium di-chromate ($K_2Cr_2O_7$) in the ratio [$CuSO_4.5H_2O$ (3%) + $Na_2Cr_2O_7/K_2Cr_2O_7$ (4%) + ($H_3BO_3$1.5%)] by weight. It came into existence as a substitute for CCA as the arsenic was too costly and environmental impacts of arsenic and its high toxicity compared to boron. But CCB, due to its leachable nature, it is only effective when being applied at comparatively higher doses.

16.4.4.5 Chromated Zinc Chloride (CZC)

The preservative is composed of sodium dichromate ($Na_2Cr_2O_7$) and zinc chloride ($ZnCl_2$) in the ratio (81.5:18.5).

16.4.4.6 Fluoro-Chrome-Arsenate-Phenol (FCAP)

These Wolman-type preservatives are mixtures of sodium fluoride and chromate, sodium arsenate and 2,4-dinitrophenol. 2,4-dinitrophenol has recently been replaced by sodium pentachlorophenate to eliminate the yellowing of treated timber. FCAP-type preservatives have been marketed under a wide number of formulations and trade names. They are Triolith, Minolith, Fluoxyth, Flunax, Tanalith U, Triolith U, Basilit UA, Osmolit U, Osmolith UA, Wolmanith UA, Trioxan U and Trioxan UA.

16.5 Wood Coatings

16.5.1 Antiweathering Chemicals

When wood is exposed to the weather unprotected, its appearance soon deteriorates. Continuous wetting and drying causes cracking and splitting, ultraviolet light degrades and breaks down wood in the surface to give products which can be washed away by the rain. Fungi and moulds also growing in the cracks and splits cause the timber to appear dirty.

16.5.2 Paints and Varnishes

Paints and varnishes give the most effective means of maintaining the appearance of wood, provide that they completely cover the wood and they are not damaged in any way. The transparent film of varnish protects the wood from getting wet and screens the surface from damaging by ultraviolet light. Unfortunately, while these coatings give good protection against rainfall, they are unable to prevent changes in moisture content resulting from seasonal fluctuations in atmospheric relative humidity. As a result, the painted wood will shrink or swell with changes in relative humidity, causing the surface coating to crack and split. Water penetrates into the wood and then staining fungi and moulds begin to colonize the surface. In a study conducted in England only 6% of over 200 varnishes tested presented uninterrupted defence for more than 1 year. Maintenance is generally essential with expensive cleaning and varnishing (Williams, 1999).

16.5.3 Water Repellents and Stabilisers

These are used to surface coat the pores of structural material to prevent the absorption of water. This will retard the ingress of water when wood is exposed above the ground. These preservatives reduce the dimensional changes in the wood as a result of moisture changes when the wood is exposed to rainwater for short periods of time. Various substances like waxes, especially paraffin waxes are the well-known water repellents used in wood preservative formulations. The aliphatic and aromatic hydrocarbon resins are inexpensive and efficient but solidify only by loss of solvent, re-dissolve by coating solvents. Natural drying oils, such as linseed oil, can also be used. Generally, a mixture of waxes, hydrocarbon resins and alkyd resins are used in order to prevent these problems. The organo-silicon compounds are the best-known water repellents but they possess many of the disadvantages of heavy organic oils and waxes. The silicones with a high degree of functionality to fix to the wood components are suitable to apply the wood giving good resistance to wetting failure (Leach & Zhang, 2004). Organo-aluminium compounds can incorporate unsaturated chains, and water repellent they can provide excellent adhesive bonding between the wood elements and alkyd systems (De Vetter et al., 2010). Commercial Manalox products are polyoxoaluminium systems. Formaldehyde treatment of wood in the presence of an acid catalyst will crosslink hydroxyl groups on adjacent chains, reducing the dimensions of wood and also the movement (Lloyd et al., 1990). Acetylation, the treatment of wood with acetic anhydride in the presence of a strong acid catalyst considerably reduces the hygroscopicity of wood and increases the resistance to fungi. These chemical treatments are successful on condition that wood is completely impregnated. Impregnation of wood with a high retention of chemicals is called bulking. Some resin systems were used in systems was used in this way as in impregnation. Polyethylene glycol waxes, such as PEG, Carbowax and MoDo, are also used in bulking. These systems are applied particularly for the stabilization of archaeological specimens and also floor blocks. Of the water-repellent formulations, the Madison formula is the best known. The formula consists of paraffin wax, pigments and boiled linseed oil binder with pentachlorophenol and zinc stearate to give water repellency, colour retention and resistance to staining by fungi and moulds. Weather resistance can be improved by using a binder as in Madison formula. In the Royal process developed for the treatment of external joinery a waterborne treatment is followed by a deep treatment with a drying oil (Mantanis, 2017).

16.6 Development of Wood Preservatives

Efforts were being put to keep away the wooden pillars from the soil and vegetation by placing them on the stone blocks. Eventually, uses of essential oils were being practised in order to protect the wood against the biological deteriorators. M. Paulet in his book entitled "conservation des Bios" enumerates 173 processes or methods that were tried, most of which proved unsuccessful. During the first quadrate of the nineteenth century, the wood samples were injected with the chemical preservatives. The need for developing preservation stemmed out of acute scarcity of wood for building ships by the British Navy (Boulton, 1885).

- **Mercuric chloride** was used by Homberg in 1705 and by De Boissiew in 1967. The use is commonly called 'kyanizing' (Boulton, 1885).
- **Copper sulphate** recommended by De Boissiew and Bordenava in 1967 and best known as 'margaryzing' (Boulton, 1885).
- **Chloride of zinc** recommended in 1815 by Thomas Wade and by Boucherie in 1837 and referred as 'burnettizing' (Boulton, 1885).
- Oily liquid preservatives used earlier were Creosote oil, carboleneum and shale oil, respectively. These wood preservatives were suggested by Hutin and Boutigny in 1848 (Boulton, 1885).

Chemical companies have moved towards the development of safer, less toxic biocides. The process of preservative development is long, taking 5 to 7 years for standardization in many countries and often requiring several years beyond that time for the development of substantial commercial use. Despite the high costs associated with these developments, a variety of biocides have recently been developed. Many are variations on existing chemicals employed in agriculture, but several have been developed specifically for wood protection. In addition, a number of older, more expensive compounds have received renewed interest (Freeman et al., 2003).

16.7 Organic and Inorganic Compounds as Wood Preservatives

Boron as borax, boric acid or disodium octaborate tetrahydrate are used as fire retardants in wood. Copper as copper carbonate, copper hydroxide, copper oxychloride, copper sulphate, cuprous oxide and copper hydroxycarbonate.

Chromium as chromium trioxide or sodium dichromate is used as admixtures in water-soluble preservatives salts. Arsenic as arsenate is used in CCA (inorganic compounds). Chlorinated phenols, chlorinated cresols and xylonols, chlorinated napthalenes, nitrated phenols and cresols, chlorinated benzenes, di-chlorodiphenyltrichloroethane (DDT) and organic mercury compound (organic compounds).

16.8 Recent Trends in the Development of Wood Preservatives

Older preservatives still account for a high percentage of the total volume of usage (Baechler, 1963). Wood, upgraded with ethanolamine, has increased fungicidal resistance (Humar et al., 2007). Eucalyptus grandis sapwood treated with chromated copper arsenate (CCA), used engine oil and neem extract provided better protection against termites. Borates are good wood preservatives for the protection of wood from decay fungi and a wide variety of insects. The only drawback was they can also be readily leached from wood under certain conditions (Freeman et al., 2003). Pre-acid treatments (sulphuric acid and phosphoric acid) with pressure was more effective for increasing of retention of both CCA and ACQ than non-pressure methods of application (Yildiz et al., 2010).

The traditional preservatives included di-decyldimethyl ammonium chloride (DDAC) and copper (II) sulphate pentahydrate ($CuSO_4.5H_2O$). The new-generation preservatives included Ammonicalcopperquat (Celcure AC 500) and micronized copper quat (MCQ). Observations on characterized changes to the surface of the all weathered samples in terms of colour change and surface roughness indicated that the treatment with new generation preservatives provided less colour change than traditional preservatives (Ozgenc et al., 2012). Vacuum treatment of pine wood with zinc oxide, zinc borate and copper oxide nanoparticles showed only nano-zinc borate was effective while the other nano-metal preparations did not inhibit mould fungi (Mantanis et al., 2014). It is essential to protect wood from degrading factors like decay, insects and fire; as well as to educate the consumer regarding new wood-treating chemistries and new products (Kaur et al., 2016).

Tripathi (2013) developed an ecofriendly wood preservative ZiBOC ($ZnCl_2$: $Na_2B_4O_7.10H_2O$:$CuSO_4.5H_2O$) which is comparable with CCA in exterior condition. Tripathi et al. (2018) studied the durability of the three timbers used in cooling towers viz., *Pinus roxburghii*, *P. radiata* and *Pseudo tsugamenziesii* as well as assessed the efficacy of three preservatives viz., ZiBOC, CCB and CCA at 2, 4 and 6% concentrations. The wood samples were reviewed and found that all three species of wood were naturally non-durable and 4% of preservative concentration was found to be its threshold level. ZiBOC exhibited maximum retention when compared to the conventional preservatives (CCA, CCB) and also the durability increased significantly.

16.9 New Generation Wood Preservatives

There are few biocides/wood preservatives which are found out to be effective and progressive against the wood degrading agents, namely:

16.9.1 Borates

These are basically considered as unfixed water-based preservatives. They include formulations prepared from sodium tetraborate, sodium pentaborate and boric acid, but the most common form is disodium octaborate tetrahydrate (DOT) (Freeman et al., 2009). Borates are used for pressure treatment of framing lumber used in areas of high termite hazard, such as Hawaii, and as surface treatments for a wide range of wood products, such as log cabins and the interiors of wood structures. They are also applied as supplemental internal treatments via rods or pastes. At higher retentions, borates are used as fire-retardant treatments for wood. Boron has some important advantages, including low mammalian toxicity, activity against both fungi and insects, and low cost. Another advantage of boron is its ability to move and diffuse with water into wood that normally resists traditional pressure treatment. Wood treated with borates has no colour or odour, is non-corrosive, and can be finished. While boron has many potential applications in framing, it is not suitable for applications where the wood is exposed to frequent wetting unless the boron can somehow be protected from liquid water. In some countries, such as New Zealand, boron can be used in applications where occasional wetting occurs and there is interest in the use of borates in slightly more exposed applications with coating requirements. There is also interest in dual treatments, in which borate treatment is followed by pressure treatment with a water-repellent oil-type preservative. Various combinations of silica and boron have been developed that appear to somewhat retard boron depletion, but the degree of permanence and applicability of the treated wood to outdoor exposures has not been well defined (Anon, 2005).

16.9.1.1 Complex Metal-Based System

Copper Naphthenate

It is an organometallic compound that is a dark-green liquid and imparts this colour to the wood. The treated wood changes its colour to light brown upon weathering. The wood may vary from light brown to chocolate-brown if heat is used in the treating process. Copper naphthenate is effective against wood-destroying fungi and insects. It has been used commercially since the 1940s for many wood products. It is a reaction product of copper salts and naphthenic acids that are usually obtained as byproducts in petroleum refining. Copper naphthenate is not a restricted-use pesticide but should be handled as an industrial pesticide (Hunt & Garratt, 1967).

Zinc Napthenate

It is used extensively as a component in over-the-counter wood preservative products. It can be formulated as either a solvent-borne or water-based preservative. Unlike copper naphthenate, zinc napthenate imparts little colour to the wood and thus is more compatible with transparent finishes. When zinc naphthenate is formulated in light solvent, the treated wood may also be paintable. But, wood treated with zinc naphthenate may have a noticeable odour, limiting its indoor use. Zinc is not as effective a fungicide as copper, and zinc naphthenate is not typically used as a stand-alone preservative for exposed structural members. Zinc naphthenate has some preservative efficacy, and it may be sufficient to protect wood used aboveground and partially protected from the weather. In Mississippi, zinc naphthenate pressure treatments have been shown to extend the life of exposed stakes, and brush treatments of a water-based zinc naphthenate significantly improved the performance of pine fully exposed to the weather. Zinc naphthenate, however, was less effective in protecting hardwoods. The addition of a water-repellent component to the treating solution appears to increase the efficacy of zinc naphthenate treatments (Lloyd & Fogel, 2005).

Bis (Tri-N-Butyltin) Oxide (TBTO)

Bis (tri-n-butyltin) oxide, commonly called TBTO, is a colourless to slightly yellow compound which is soluble in organic solvents but insoluble in water. This preservative has lower mammalian toxicity, causes less skin irritation, and has better paintability than pentachlorophenol, but it is not effective against decay when used in ground contact. Therefore, TBTO is recommended only for aboveground use, such as millwork. It has been used as a marine antifoulant, but this use has been almost eliminated because of the environmental impact of tin on shellfish (Shiozawa, 1991).

16.9.2 Quaternary Ammonium Compounds

16.9.2.1 Didecyldimethylammonium Chloride (DDAC)

It is a compound that is effective against wood decay fungi and insects. It is soluble in both organic solvents and water and is stable in wood as a result of chemical fixation reactions. It is currently being used as a component of ammoniacal copper quat (ACQ) for aboveground and ground contact (Kartal et al., 2005).

16.9.3 3-Iodo-2-Propynyl Butyl Carbamate (IPBC)

It is a preservative that is intended for nonstructural, aboveground use only (Ex: Mill work). It is not used for pressure-treating applications such as decks. The IPBC preservative is included as the primary fungicide in several water-repellent-preservative formulations under the trade name Polyphase and marketed by retail stores. However, it is not an effective insecticide. Waterborne and solvent-borne formulations are available. IPBC is also being used in 14:9 combination with didecyldimethylammonium chloride in a sapstain–mould formulation. IPBC contains 97% 3-iodo-2-propynyl butyl carbamate, with a minimum of 43.4% iodine (Kartal et al., 2005).

16.9.4 Polymeric Xylenol Tetrasulphide (PXTS)

It has been listed by the American Wood-Preservers Association as an oil-borne treatment. It has low toxicity to mammals and the available data shows good efficacy. Thus, this could be used as a replacement for creosote or other oil-type preservatives.

16.9.5 Azoles

16.9.5.1 Cyproconazole

It is a water-based fungicide used to protect above-ground wood. Cyproconazole does not protect wood from insects. Although cyproconazole is used as a fungicide on some crops, many of the wood preservative formulations are not intended for use on wood that comes in contact with food. Some cyproconazole wood preservatives also contain the antimicrobial didecyldimethylammonium chloride (DDAC). Cyproconazole has been approved by EPA for surface application or pressure treatment of wood for above-ground uses, including siding, plywood, millwork, shingles, lumber and other uses (Nicholas & Schultz, 1994).

16.9.5.2 Propiconazole

It is an organic triazole biocide that is effective against wood decay fungi but not against insects. It is soluble in some organic solvents, but it has low solubility in water and is stable and leach resistant in wood. It is currently being used commercially for aboveground and sapstain control application in Europe and Canada.

16.9.5.3 Tebuconazole (TEB)

It is an organic triazole biocide that is effective against wood decay fungi, but its efficacy against insects has not yet been evaluated. It is soluble in organic solvents but not in water, and it is stable and leach resistant in wood. Currently, TEB has no commercial application.

16.9.6 Agrochemicals

16.9.6.1 Chlorothalonil (CTL)/[Tetrachloroisophthalonitrile]

It is an organic biocide that is used to a limited extent for mould control. It is effective against wood decay fungi and wood-destroying insects. The CTL has limited solubility in organic solvents and very low solubility in water, but it exhibits good stability and leach resistance in wood. This preservative is being evaluated for both aboveground and ground contact applications.

16.9.6.2 2-(Thiocyanomethylthio) Benzothiozole (TCMTB)

It has been used for many years as an anti-sapstain formulation and millwork preservative. It has been formulated in both solvent-based and water-based forms; the solvent-based formulation is more prevalent for the treatment of millwork.

16.9.6.3 Isothiazolones

These are a class of organic compounds often used for mould control. They are sometimes added to wood preservatives for this purpose and are also used as additives to paints and coatings. One of these compounds, 4,5-dichloro-2-*N*-octyl-4-isothiazolin-3-one (DCOI), has been evaluated fairly extensively and is currently used as a marine anti-fouling agent in paint films. As with other oil-soluble preservatives, the properties of wood treated with DCOI are somewhat dependent on the type of solvent used. The treatment may impart a light brown colour to the wood. DCOI has a noticeable odour and the treated wood may have some odour, depending on the concentration of the treating solution. In some applications, skin sensitization can be a concern (Nicholas & Schultz, 1994).

16.9.7 Uncomplexed Copper Systems

16.9.7.1 Alkaline Copper Quaternary (ACQ)

It is one of a number of recent water-based preservatives developed to address environmental concerns about the use of arsenic and chromium in treated wood. Several formulations of ACQ have been developed and marketed but all share a similar composition. The active fungicide and insecticide components in all ACQ formulations are copper and the quaternary ammonium compounds ('quats'). Copper provides the primary fungicide and insecticide activity in ACQ formulations, while the quaternary ammonium compounds ('quats') provide additional protection against copper tolerant fungi and insects. Alkaline formulating agents, particularly ammonia, have the ability to swell wood cell walls and so improve the penetration of chemicals into wood.

16.10 Environmental Impacts of Wood Preservatives

Preservatives meant to use for outdoors have certain techniques in order to retain the active ingredients in the wood to curtail the leaching activity. But, some amount of active component present in the wood preservatives usually leaches out from the wood. The intensity of leaching of wood barely depends on factors like fixative conditions, preservative retention, exposure, size and shape of the wood. Active constituents present in wood preservatives are lethal to numerous living organisms considerably at a higher concentration. But, laboratory studies indicate that the levels of preservatives leached from treated wood generally are too low to create a biological hazard. Almost all kinds of wood treated with preservative release some quantities of active constituents to the environment. These constituents can be found in soil or sediment samples too (Lebow, 2010).

United State Environmental Protection Agencies (USEPA) were using preservatives like lumber creosote, inorganic arsenical and pentachlorophenol for the treatment. It was realized that the pentachlorophenol and inorganic arsenicals were hazardous to human beings and was even restricted not to use as preservatives but as pesticides at a limited range. The wood treated with CCA should not be burnt, as the smoke was extremely lethal to human being. The nymphs of *Potamanthusluteus* collected from the badly contaminated site of Kymijoki River, Southern Finland in 1997 had generally darkened gills, probably specifying impacts of pollution (Dobbs & Grant, 1978). Significantly lower lymphocytes, white blood cell count and serum globulin were recorded in the wood treatment plant—neighbours who were in consistent exposure with pentachlorophenol and dioxin (Heikkila et al., 1987). An extensive evaluation on CCA-related cancer risk was conducted by the Environmental Risk Management Authority of New Zealand (ERMANZ) in 2003. The studies comprised of five major studies which were updated as the human cancer potency factor developed by the National Academy of Sciences Natural Research Council in 2001. It was reported that the CCA treated wood containing inorganic ions were indirectly increasing the leaching activity. The pH of the water can also affect the leaching of the preservatives. Leaching of CCA significantly increases when the pH of the leaching water is dropped to below 3, and the wood itself also initiates to degrade. Wood preservatives can be harmful to humans if not properly handled. The exposure routes by which they can enter the human body are inhalation (vapour, dust, aerosol, etc.), ingestion (solid and liquid), ocular exposure and through the skin (vapour, liquid and solid). A number of studies have examined the effects of wood preservatives on settlement patterns, growth and biomass development of human of environments. The majority of leaching from wood when treated with waterborne preservatives, the rate and overall amount of leaching from a given product is also affected by preservative penetration and retention and by the surface area of the product (Marer & Grimes, 1992). Randerath et al. (1996) warned that about 250 wood preserving sites are present only in the United States, wherein it requires immediate remediation. These sites consist of WPW (Wood preserving waste) chemicals which are lethal to living beings. They are carcinogenic, mutagenic, neurotoxic, immunotoxic, hematoxic and hepatotoxic. It also causes skin and mucous membrane irritation. The waste discharges and the emissions from these sites produce an immense amount of naphthalene, benzene and PAHs. Due to these emissions, neighbourhood environment would be polluted. The affected individuals possess symptoms like nausea, eye and throat irritation.

Utilizing chemical preservatives do show toxicity against a wide spectrum of microorganisms, but it affects human health as well. Even the most benign chemicals present in surplus may pose health hazards on prolonged contact. Nevertheless, the preservatives recommended for a particular use are carefully assessed for their possible hazards to the environment as well as workers exposed to the same. In the upcoming days, care needs to be taken with respect to the disposal of preservatives. The general phobia that CCA formulations containing arsenic are dangerous and those containing chromium are carcinogenic has no scientific or practical data to support the same. The new formulations containing the so-called environmentally safe molecules are not hazard-free. Pentachlorophenol and its sodium salt were used to protect wood against sap stain, was found to contain some dioxins and their use has been restricted in many countries. One of the substitutes recommended was TCMTB (2-(thiocyanomethylthio) benzothiazole), which is a much expensive chemical. If one goes through the MSDS (Material Safety Data Sheet) of this chemical, it is reported that contact with eyes can produce permanent blindness. Chlorpyriphos is another chemical introduced a few years back for termite control in soil poisoning and recommended as an insecticidal component in light organic solvent type preservatives which was also found to be affecting the nervous system of children (Taylor & Cooper, 2003).

Application of preservatives like copper chrome arsenic (CCA), copper chrome boric acid (CCB), ammoniacal copper zinc arsenate (ACZA), ammonical copper quaternary (ACQ) and ammoniacal copper citrate (ACC) had impacted the settlement of barnacles, oysters and bryozoans (Tarakanadha et al., 2002). Wood treating plants released naphthalene in large amounts in the atmosphere. It has been found that the plant produced around 2.2 mg/m^3 of the total 3.7 mg/m^3 of airborne creosote vapour in the work area. The chemical waste disposed from the wood preservatives causes an irreversible damage to the DNA. There are around 12 chemical constituents present in the vapour phase of creosote like naphthalene, methyl naphthalene, indene, methyl styrene, toluene, xylene, phenol, benzothiophene, di-phenyl, acetanapthalene, creosols and xylenols, respectively. Long-term low-level exposure of these chemicals will cause neurological symptoms and abnormalities to the exposed subjects at the genetic level. The use of natural materials such as traditional tar, wood oils, tannins and plant extracts for wood preservation can solve this problem to a considerable extent (Lebow, 2010).

16.11 Strategies

(a) Use less preservative; comply with regulations and guidelines at all stages of the life cycle for certain preservatives.
(b) Reduce use of arsenic, chromium, creosote and pentachlorophenol containing preservatives and probably in the longer term, copper-containing preservatives. In parallel with this, the trend is for introduction of a much broader suite of alternatives, with main focus on organic preservatives.
(c) Popularization of eco-friendly wood preservatives.
(d) Recover inorganic preservatives from treated wood by collecting and treating ashes and condensate from co-generation or incineration facilities (Italy and Finland).
(e) Require manufacturers to take full life responsibility for their products (Cooper, 1999).

16.12 Wood Preservative Treatment Methods

It is necessary for wood to be treated with the appropriate preservatives for the protection against the bio-deteriorating organisms. Wood like rubber wood is highly susceptible to almost all kinds of fungi, insects, and termites and so on. Untreated logs are very prone to attacks by the fungi and borers. The action of these kinds of bio-deterioraters makes the wood less attractive and in turn makes it of less or no use. The wood therefore needs to be treated with the preservatives which are cost-effective and less harmful to the environment (Kumar & Dev, 1993).

The application of wood preservatives can be categorized into two types:

(a) Non-pressure treatment.
(b) Pressure treatment.

16.12.1 Non-pressure Treatment Method

Non-pressure processes are carried out without the use of artificial pressure under the atmospheric pressure. There are around six methods under non-pressure treatment namely

16.12.1.1 Brush Coating

The simplest method of applying a preservative is brushing and is normally used for preserving small individual items as shown in Fig. 16.1. Brushing is a convenient

Fig. 16.1 Brush coating of samples

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).

16.12.1.2 Spraying

Spraying is a 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 into wood is more in spraying compared to brush coating. 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).

16.12.1.3 Dipping

This method consists of immersing wood in a preservative solution for 2–3 days as shown in Fig. 16.2. It allows better penetration into wood compared to brush coating and spraying. There is little protection against termites and it is not recommended for wood used in contact with the ground.

16.12.1.4 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 into wood. Therefore, the absorption takes place during the cooling period.

Fig. 16.2 Dipping of samples

16.12.1.5 Sap Displacement Method

Sap displacement method can only be applied to green round timbers and bamboo. It uses the hydrostatic pressure due to gravity to force the wood preservative from the butt end of the round timber. It is made to flow along the length of the wooden pole along the flow of sap stream as shown in Fig. 16.3a, b. The poles to be treated are made to stand inclined or vertical in solutions of water-soluble wood preservatives for 2 to 4 days and thereafter inverted for the same period of time (Tewari et al., 1967). This is an excellent and very simple onsite treatment standardized at Institute of Wood Science and Technology, Bangalore. Rural people, who cannot afford to follow any one of the above treatments, can employ the simple sap displacement technique for treating green bamboos/poles. This is done by keeping the butt end of freshly felled bamboos with in a tub containing the preservative solution (6 to 8%) to a depth of 30 to 40 cm after 24 to 48 h the bamboos/poles are reversed with the top end submerged in the solution. They can be removed after 24 to 48 h of reversal.

After the treatment, bamboos/poles must be stored in a rack under the roof to avoid direct sunlight and rain for at least 2 weeks. The bamboo/poles must be stored in shades. The rack must support bamboo in horizontal not in vertical position. If bamboo dries in vertical position the preservative solution may leak out. During these periods of slow drying process, the preservative will diffuse from sap to the surrounding tissue of the bamboo with preservatives like CCA and CCB get fixed. Green bamboos cut fresh in the farm can be treated by sap displacement within 24 to 48 h, from the time of felling. If there is delay between felling and treatment the latter can be taken up by keeping felled green bamboos soaked in fresh water tank, stream, channel or trough for a period ranging from 1 to 2 days. Bamboo treated in green

Fig. 16.3 Sap displacement treatment method (**a**) Eucalyptus poles treated by sap displacement; (**b**) Bamboo poles treated by sap displacement

condition was found effective against the attack of fungi and wood-boring insects. These insects cause severe damage in untreated bamboo which eat the nutritious materials inside the bamboo and weaken the bamboo structures.

16.12.1.6 Diffusion Treatment

Diffusion treatment with boron compounds is one of the simplest, cheapest and effective ways of protecting wood from biodegradation (Dhamodaran & 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 a typically slower method of treatment. This involves some uptake of preservative by bulk flow and thereafter preservative is further distributed by diffusion.

16.12.2 Pressure Treatment

Pressure treatment processes are carried out by applying a positive external pressure to force the liquid into the pores of the wood (Findlay, 1985). The wood is placed into an airtight cylinder and immersed in a preservative as shown in Fig. 16.4. By increasing the pressure drives the chemical into the wood. There are several types of high-pressure processes namely.

16.12.2.1 Bethel or Full Cell Process

This is the normal process used when treating with water-born solutions. The main steps in the full cell process are:

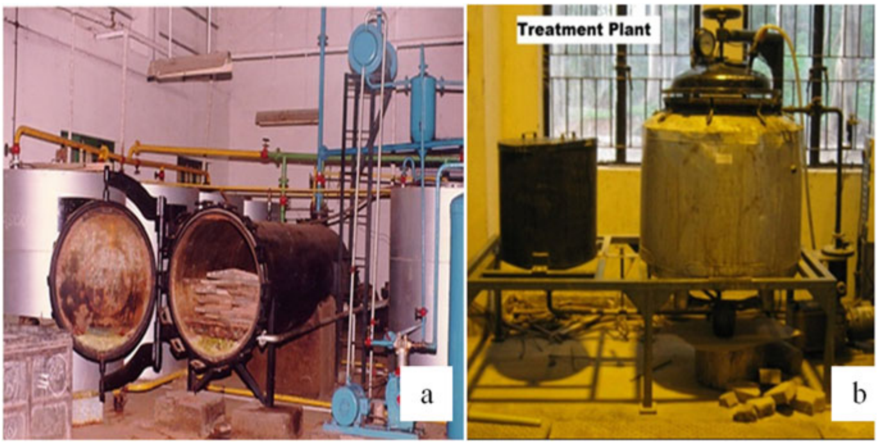

Fig. 16.4 Pressure treatment method: (**a**) pressure treatment cylinder (large scale); (**b**) pressure treatment cylinder (small scale)

(a) The charge of wood sealed in the treating cylinder, and a preliminary vacuum is applied for 30 min or more to remove the air from the cylinder and as much as possible from the wood.
(b) The preservative, previously heated to somewhat above the desired treating temperature, is admitted to the cylinder without admission of air.
(c) After the cylinder is filled pressure is applied until the required preservative is obtained.
(d) When the pressure period is completed the preservative is withdrawn from the cylinder (Wallinger et al., 1974).

16.12.2.2 Empty Cell Process

There are two main types of empty cell processes which are called ruepning and lowery processes. In both processes there is no initial vacuum applied, the preservative is forced into 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 (1) preliminary air pressure applied (2.0–5.0 kg/cm^2), (2) fill cylinder/hold air pressure, (3) build up pressure, (4) maximum pressure held, (5) release pressure, (6) empty cylinder of preservative, (7) final vacuum period and (8) release vacuum.

Pressure treatment of wood is performed in steel pressure cylinders or vessels which range in size from 1.5 m to 3 m in diameter and up to 20 m in length, and are capable of withstanding pressures up to 14 bars. The cylinders are normally mounted on saddle blocks, and equipped with instruments which measure and record processing temperatures/vacuums and pressures. Vacuum pumps and pressure pumps capable of applying vacuum of more than 600 mmHg and pressure of up to 14 bars, respectively are part of the necessary equipment. In addition, preservative storage and mixing tanks are also required, and are normally in the form of steel cylindrical tanks. In Malaysia, the commonly used pressure process for impregnating wood with preservatives against fungal decay and insect attack is the vacuum-pressure process (also known as the Bethell process). The oscillating pressure method (OPM) is also being used. The OPM which rely on the quick changes of vacuum and pressure phases is generally fully automatic in operation, whereas the vacuum-pressure process is mostly semi-automatic. There is a trend now for preference of the automated process for increase in efficiency and efficacy of treatment. The main steps in the lowery process include: (1) fill cylinder with preservative at atmospheric pressure, (2) build up pressure, (3) maximum pressure held, (4) release pressure, (5) empty cylinder of preservative, (6) final vacuum preservative and (7) release vacuum.

16.12.2.3 Boucherie Process

Dr. Boucherie of France developed this process in 1838 for treating green timber or bamboo. This is the most commonly used sap displacement technique where we can treat bamboo quickly in large number. A suitable container is taken for keeping the water-soluble treating solution. The container is provided at the bottom with side tubes fitted with stopcocks and rubber tubes to which green bamboos (along with

Fig. 16.5 Regular and modified Boucherie treatment process

branches) are attached as shown in Fig. 16.5. In order to secure leak-proof contact between the rubber tubes and the bamboos a suitable metallic clamps or other devices are provided. The tank is also fitted with a screw cap which has a suitable valve attached to it. The tank is then filled with treating solution to about two-thirds of its volume and after tightening the cap; air is pumped in through the valve to a pressure of 1.0 to 1.4 kg/sq.cm. It is easily measured by pressure gauge. At this pressure range, the treating liquid forces the sap out of the walls and the preservative displaces the sap, which is then forced out at the narrow end. The treatment is stopped when the colour of the preservative in the drip is nearly the same as that of the solution in the reservoir. After a few preliminary experiments, the concentration of the treating solution and the period of treatment are fixed to obtain requisite absorption of the preservatives and the poles/bamboo is taken off when the treatment is complete (Grover, 1957). The whole treatment will complete within 4 to 8 h.

16.13 Conclusion

The great variety of wood-destroying insects and fungi in the environment constitutes a much greater danger for wood. High temperature and high atmospheric humidity, together with the extraordinarily large number of nondurable wood species are vulnerable to degradation. A considerable amount of this value could be saved through expanding the preservative treatment of wood. Wood preservation makes it possible to reserve precious durable species. Employing chemical complexes as wood preservatives could reduce the impact caused by the bio-deteriorators. Nevertheless, the preservatives obtained from the naturally available plants and its products are more efficient, eco-friendly and need to be produced in large quantities. The major issue for the future is to develop more understanding on the chemistry and different treatment mechanism of wood, in order to help researchers reach a balance between the treatment effectiveness, the global environmental health impacts and the economic costs of the process. By utilizing the wood preservatives very cautiously and also by considering the environmental impacts, the harm caused to the beings living around can be reduced.

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