FRIM TIMBER TECHNOLOGY BULLETIN
NO. 119, 2022
ISSN: 139-258

WOOD VINEGAR AS SUSTAINABLE AND NATURAL WOOD PRESERVATIVE

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INTRODUCTION

Wood vinegar, also called as pyroligneous acid or liquid smoke, is a by-product during high temperature (300–700°C) carbonization of woody biomass (Figure 1) including non-wood (e.g. bamboo, oil palm etc.) in the absence of oxygen (O_2) (Shen et al. 2020). Generally, wood vinegar is produced during the manufacture of charcoal. It is an acidic reddish-brown aqueous liquid (Figure 2) obtained by clarifying the liquid product of the carbonization. Wood vinegar is often used as insect repellent, ingredient in medicines, odour remover, wood preservative, a mordant in the dyeing process, soil fertiliser, plant growth promoter or inhibitor and animal feed additive.

Figure 1 Woody biomass materials for charcoal and wood vinegar production

Figure 2 Colour of wood vinegar

The demand for wood in charcoal production is directly proportional to the demand for wood vinegar. Wood fuels accounted to about half (49%) of all roundwood produced in 2018 on a global scale. Seventeen percent (17%) of all the wood used as an energy source is converted to charcoal, which accounts to about 53 million tonnes of wood charcoal (Firouzbehi et al. 2021). In 2020, Malaysia exports USD 2.25 million worth of vinegar and their substitutes to Singapore, China, United Kingdom, Hong Kong, Brunei and Bangladesh (Oec 2022).

The world market size is increasing as the demand for chemical-free pesticides had immensely contributed to demand for wood vinegar (Figure 3). The agricultural field emerged as the largest wood vinegar application industry, and it accounted for 43.7% of the global revenue share in 2016. Based on the forecast, the United States (US) market is anticipated to grow at a compound annual growth rate (CAGR) of 5.9% from 2017 to 2025, reaching USD 1.05 million by 2025. The rise in future demand is contributed by the increase in the sales of organic products by the millennial generation (Grandviewresearch 2022).

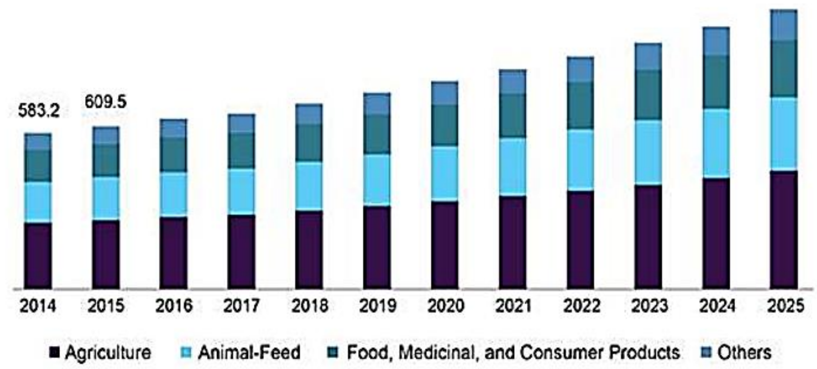

Figure 3 US wood vinegar market revenue by end-use, 2014-2025 (Thousand USD) (Grandviewresearch 2022)

Wood products are continually used in indoor and outdoor applications due to their unique characteristics although there are other materials (plastics, metals etc.) that can be used. However, wood products are susceptible to degradation due to attacks by termites, fungi and wood borers which will result in significant loss of economic and material resources. Therefore, preservation of wood is necessary to minimise deterioration, extending the service life of the wood products. However, since 2004, the European Union and the US Environmental Protection Agency no longer allow the use of wood that is pressure treated with synthetic chemicals such as chromated copper arsenate (CCA) for use in residential applications due to public concerns over arsenic exposure (Theapparat et al. 2015). Thus, the development of alternative environmental-friendly green wood preservatives is urgently needed to replace the synthetic chemicals.

Many studies have been done on wood vinegar as wood preservatives. Most sources of vinegar have been recognised as safe natural inhibitors with a wide range of bioactivity, making them particularly suitable for antifungal, termiticidal and repellent applications (Amen-Chen et al. 2001, Baimark & Niamsa 2009, Ma et al. 2011, Oramahi & Yoshimura 2013, Velmurugan et al. 2009a). Some of the possible vinegar sources are oil palm trunk (Oramahi et al. 2018), bamboo (Theapparat et al. 2015), pong-pong tree (*Cerbera odollam* Gaertn.), palm kernel cake and cassava pulp residue (Weerachanchai et al. 2011), walnut shell (Ma et al. 2011) etc. In addition, wood vinegar exhibits high levels of antimicrobial activity against various microorganisms (Hwang et al. 2005), along with significant antioxidant activity (Van et al. 2000, Yang et al. 2016). Forest Research Institute Malaysia (FRIM) had also conducted a study on wood vinegar obtained from slow pyrolysis of *Dyera costulata* (jelutong). The study evaluated the potential of using wood vinegar as a natural biocide against termites which are one of the most damaging agents.

PRODUCTION OF WOOD VINEGAR

Carbonization is a slow pyrolysis process. This process has been widely used in the conversion of agricultural and forestry residues into high value-added products via destructive distillation or dry distillation. During the carbonization process, the raw material is heated up in oxygen-free environment and volatile elements will form three-phase matters, i.e., charcoal, liquid by-product which is wood vinegar or pyroligneous acid, and fuel gas at the end (Figures 4, 5 and 6) (Wu et al. 2015). This pyroligneous acid is widely used in agricultural and veterinary purposes. In Asia, wood vinegar products are mostly from China. Furthermore, wood vinegar-based pesticide market is well established in Japan and other Asian countries such as Thailand, Cambodia and China (Theapparat et al. 2015).

Figure 4 Carbonization via pyrolyser

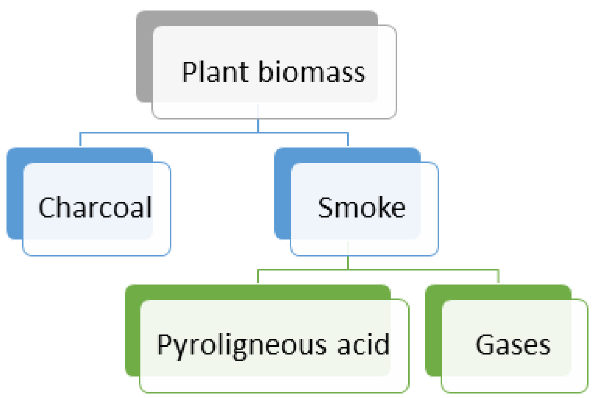

Figure 5 Products from pyrolysis of plant biomass

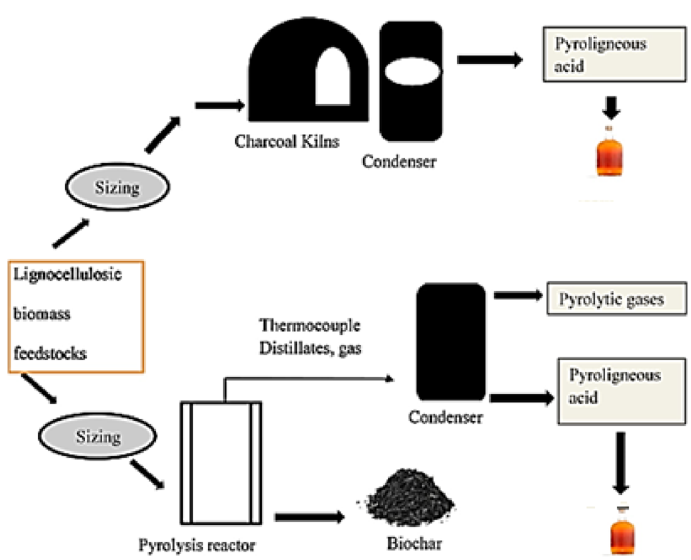

Figure 6 Production of pyroligneous acid (Grewal et al. 2018)

WOOD VINEGAR PROPERTIES

Wood vinegar is a complex structure containing rich source of carbon and oxygen molecules. It consists of a large proportion of water (80-90%) and a small proportion of more than 200 organic compounds (Grewal et al. 2018, Wu et al. 2015) (Figure 7). The main compounds of wood vinegar are acetic acid, organic acids, phenolic, alkane, alcohol and ester (Jothityangkoon et al. 2008). This water-soluble wood vinegar has a low pH of 3 and specific gravity between 1.005–1.050. This acidic condition is due to acetic acid (50%) as the main compound while the phenolic group causes wood vinegar to have a smoky odour. The presence of phenolic compounds and acetic acid in wood vinegar allows it to be used as an antifungal agent when incorporated with wood polymers. It can also change the properties of wood from hydrophilic to hydrophobic (Firouzbehi et al. 2021, Grewal et al. 2018, Hagner et al. 2013, Kiarie-Makara et al. 2010). Among the factors that determine the physicochemistry and biological activity of wood vinegar are chemical composition of the biomass, pyrolysis parameters (heating rate, temperature), raw material source (different wood species produce different compounds) and method of filtration (Theapparat et al. 2018).

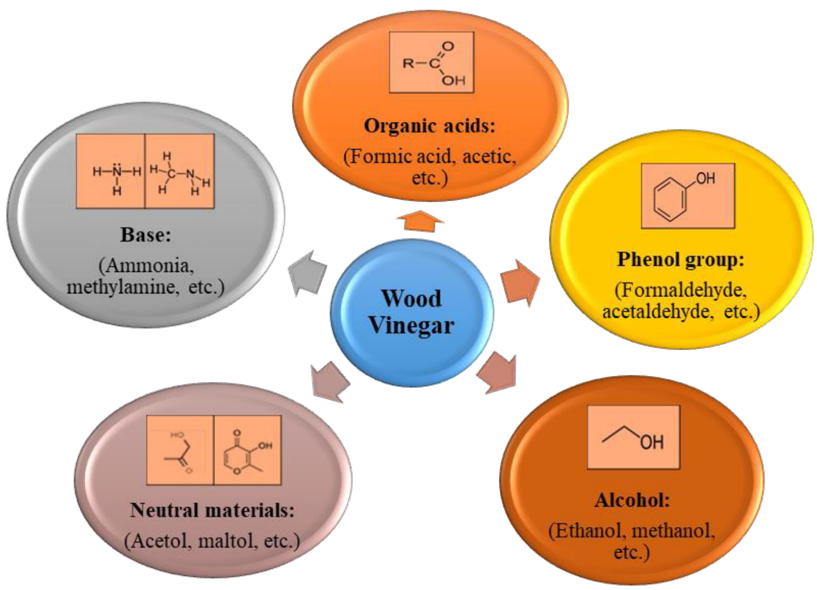

Figure 7 Typical chemical compounds of wood vinegar produced from pyrolysis process

APPLICATION OF WOOD VINEGAR AS WOOD PRESERVATIVES

Wood vinegar can be obtained from many different sources of wood biomass and are recognised as safe natural inhibitors in various applications (Velmurugan et al. 2009a, Kiarie-Makara et al. 2010). Its effectiveness does not come from a single compound, but from multiple effects of various compounds, including the ability to control diseases and pests when used in treating wood products. Wood vinegar is widely used in agriculture for soil quality improvement, pest elimination, plant growth control (able to accelerate development of roots, stems, tubers etc.), fertiliser and seed germination. It can also help to boost crop defences against diseases and increasing the population of beneficial microbes (such as *bacilli, actinomyces* and *trichoderma*) when applied to the soil (Echocommunity 2022).

A few control technologies have been developed to prevent wood discolouration due to fungi attack as well as termite infestation. Wood vinegar from *Rhizophora* sp. has been reported to have repellent properties against brown rot (*Gloeophyllum trabeum* and *Coniophora puteana*) and white rot fungi (*Coriolus versicolor* and *Lentinus* *sajor-caju*) (Nor Azrieda et al. 2015). Velmurugan et al. (2009b) reported that wood vinegar produced from bamboo and broad-leaved trees were effective against sapstaining fungi (*Ophiostoma flexuosum*, *O. tetropii*, *O. polonicum* and *O. ips*) at minimum concentrations (0.10–1.00%) while *Vitex pubescens* displayed antifungal effect against white rot fungus (*Trametes versicolor*) and brown rot fungus (*Fomitopsis palustris*). Wood vinegar also showed termiticidal activity and repellent effect against *Reticulitermes speratus* and *Coptotermes formosanus* (Oramahi & Yoshimura 2013). Pyroligneous acids from *Eucalyptus camaldulensis, Leucaena leucocephala, Azadirachta indica, Hevea brasiliensis* (rubberwood) and *Dendrocalamus asper* (bamboo) also exhibited antifungal activity (growth inhibition, minimum inhibitory and fungicidal concentration) of two white rot fungi (*Trametes versicolor* and *Rigidoporopsis amylospora*), brown rot fungus (*Gloeophyllum trabeum*) and sapstain fungus (*Botryodiplodia theobromae*) (Theapparat et al. 2015). A study on the effectiveness of wood vinegar from oil palm mesocarp fibers (OPMF) on antifungal activity found that it was toxic to *Ganoderma boninense, Aspergillus fumigatus* and *Trichoderma asperellum* (Sharip et al. 2016). Adfa et al. (2020) reported that wood vinegar from *Cinnamomum parthenoxylon* exhibited antifungal activity against white rot fungi (*Schizophyllum commune*) and brown rot (*Fomitopsis palustris*).

However, not many studies have been done with respect to the application of wood vinegar against termite infestation. As for antitermitic properties (Figure 8), high termiticidal effect against Japanese termite, *Reticulitermes speratus* was exhibited by wood treated with wood vinegar (Yatagai et al. 2002). Wood vinegar from oil palm trunk was reported to exhibit anti-termite properties against *Coptotermes formosanus* workers in the no-choice experiment at relatively high concentrations (10% concentration was required to achieve 100% mortality) (Oramahi et al. 2018). Indrayani et al. (2012) found that higher temperature (450°C) pyrolysis process of oil palm empty fruit bunches (OPEFB) produced vinegar that causes 100% mortality of *C. curvignathus*. Wood vinegar obtained from *Cinnamomum parthenoxylon* was also toxic against *C. curvignathus* (Adfa et al. 2020). Roszaini et al. (2021) also performed a study on utilisation of wood vinegar derived from the slow pyrolysis of *Dyera costulata* (jelutong). They investigated the wood vinegar's toxicity against subterranean termites, *C. curvignathus,* one of the most destructive insects to wood and wood products.

Figure 8 Wood vinegar as natural wood preservative and anti-termite application

CONCLUSION

Pyrolysis of plant biomass is an effective approach to dealing with forestry and agricultural wastes. It produces wood vinegar as well as other bioproducts such as charcoal. Anti-fungal, anti-termite, antioxidant, pesticide and plant growth-promoting properties are found in wood vinegar. Wood vinegar is environmentally friendly and can be used as a long term assistance to farmers. Ongoing study and new information on wood vinegar showed many potential and future opportunities for production and use of wood vinegar in protecting wood against biodeterioration agents (fungi, termites and wood borers). Extensive use of wood vinegar can result in healthier ecosystem, as well as greater socioeconomic and health benefits.

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Wood vinegar, a liquid by-product of slow pyrolysis of wood or other lignocellulosic biomass, has been widely used in various agricultural applications, including crop enhancement and as pesticide. Wood vinegar could be used as long-term wood preservative to protect against rot, fungi and termites. This article is expected to generate discussions and raising public awareness on the vast prospects of wood vinegar research and applications.

Series Editor : Mohamad Omar MK & Ong CB
Managing Editor : Vimala S
Typesetter : Rohayu Y

Set in Times New Roman 12

Printed by Publications Branch, Forest Research Institute Malaysia
52109 Kepong, Selangor