EFFECTS OF FREE FORMALDEHYDE EMISSION REDUCTION BY AMMONIA FUMING ON PHYSICAL AND STRENGTH PROPERTIES OF PARTICLEBOARDS MADE FROM FORMALDEHYDE BASED RESINS

[1]Orori, B. O., [2]Gillah, P., Etiégni, [1]L., [1] Senelwa, K., [1]Mbego, J. O. and [1] Balonzi, K.

[1]Moi University Department of Forestry and Wood Science
[2] Sokoine University of Agriculture, Department of Wood Utilization
Corresponding author email: benorori@yahoo.com

ABSTRACT

Particleboards made using formaldehyde adhesives cause substantial emission of free formaldehyde over time. Free formaldehyde is harmful to the user's health and it also weakens internal bonds of particleboards in use. Emissions levels of formaldehyde lie between 0.8 to 2.2 g/m^3 of indoor air in particleboards constructed homes. This study was carried out to quantify the amount of free formaldehyde in particleboards from Raiply Ltd in Eldoret, suggest possible ways to reduce the emissions and determine the effect of the treatment on physical and mechanical properties of the particleboards. Five samples were selected randomly and, different sections of the boards were prepared and soaked in distilled water for different times. Samples fumed with ammonia at different durations from 15 to 60 minutes were subsequently soaked for 1 to 24 hours to determine water absorption. High Pressure Gas Chromatography (HPGC) was used to quantify free formaldehyde present in each leachate. Ammonia treated and untreated samples were tested for both physical and mechanical properties at the Kenya Bureau of Standards. The study revealed that fuming particleboards with ammonia reduces the amount of free formaldehydes, on average, by 100%. Ammonia fuming reduces particleboards thickness swelling by between 14.01 and 11.5% and water absorption by between 95.6 and 90.5%. the fuming increased MOE of particleboards from 2689.9 to 3405.3 kN/mm and MOR from 10.3 N/mm to 9.3 N/mm. Ammonia fuming should therefore be used to reduce free formaldehyde emission indoor. It's recommended that further studies be carried out to determine long-term effect of ammonia fumes on particleboards.

Key words: Particleboards, ammonia fuming, formaldehyde adhesives and emission

INTRODUCTION

Heavy use of formaldehyde based adhesives such as Urea formaldehyde (UF), Phenol formaldehyde (PF) and Melamine Formaldehyde (MF) in wood based products and synthetic fibres results in noticeable formaldehyde odours in most homes and plants manufacturing such products. In homes, the significant sources of formaldehyde are pressed wood products made using UF resins adhesives. Pressed wood products made for indoor uses include particleboards (used as sub-flooring, shelving, in cabinet and furniture); hardwood plywood panelling (used for decorative wall covering, cabinets and furniture); and medium density fibreboard (used for drawer fronts, cabinets, and furniture tops). Medium density fibreboard contains a higher resin-to-wood ratio than any other UF pressed wood product and is generally recognized as being the highest formaldehyde-emitting pressed wood product (EPA 1991; Brown 1999; Risholm-Sundman 1999; Nathalie *et al.* 2003).

Other sources of formaldehyde include paper products, cosmetics, and permanent-press fabrics including clothing and drapes that are made of formaldehyde based adhesives (California EPA 1991). Although free formaldehyde is present in most formaldehyde based resins, pressed woods that contain PF and MF resins generally emit formaldehyde at considerably lower rates than those containing UF resin. UF resins readily hydrolyze and liberate more than twenty times free formaldehyde than PF (George 1984; Chang *et al.* 2002).

Formaldehyde emissions generally decrease as product age increases. Studies indicate that homes constructed with particleboards bonded by UF comprise of 0.8 to 2.24 mg/m^3 of indoor air with the highest concentration in newer homes (Lawrence and Wellorn 1979). When the products are new, high indoor temperatures or humidity can cause increased release of formaldehyde from these products (Nevers and Lehmann 1968).

Emissions of formaldehyde to the atmosphere have a great effect to humans and animals within the vicinity. Formaldehyde, a colourless, pungent-smelling gas, can cause watery eyes, burning sensations in the eyes and throat, nausea, and difficulty in breathing in some humans exposed at elevated levels (above 0.1 parts per million). High concentrations may trigger attacks in people with asthma (George 1985). It has also been shown to cause cancer in humans and animals. Other health effects include nose and throat irritation, wheezing and coughing, fatigue, skin rash and severe allergic reactions (EPA 1991; Sherman and Hodgson 2004)).

Steps to reduce exposure have been taken including use of "exterior-grade" pressed wood products (lower-emitting because they contain phenol resins, not urea resins), use of air conditioning and dehumidifiers to maintain moderate temperature and reduce humidity levels and increase ventilation, particularly after bringing new sources of formaldehyde into the home (Keil *et al.* 2001; Semra *et al.* 2004). The Forest Products Research Society (1981) reported the use of a chemical that reacts with formaldehyde to give non-polluting compound.

Significance and Objectives of the Study

There is an increased use of particleboards in both construction and furniture industries due to the dwindling supply and inadequate availability of mature and large diameter logs for large and quality products (Semra *et al.* 2004). Bonding of panel boards is mainly by use of cheap and most available UF adhesives, which leads to increased exposure of innocent consumers of the products. Therefore, there is need to seek ways of reducing this exposure and determining the effect of such treatments on the quality and performance of the products. This paper is aimed at quantifying and reducing the level of emission of free formaldehyde by ammonia fuming of the UF bonded particleboards and consequently determining the effect of the treatment on the physical and strength properties of the particleboards.

MATERIALS AND METHODS

Particleboards for the study were obtained from Raiply Ltd. in Eldoret Kenya, which is the main manufacturer of the products in the country. Simple random sampling was adopted to select the ten particleboards from different dates of manufacture used in the study. Quantification of free formaldehyde in particleboards was determined by cold and warm soaking method. Fifty samples (20cm by 20cm) each were soaked in cold (at 23^{o}C) and warm distilled water (at 60^{o}C) for different durations to allow free formaldehyde to dissolve. The levels of cold soaking were one, two and twenty-four hours and warm soaking were 15 minutes, 30 minutes and 60 minutes. Ammonia fuming was done at various levels for all samples for various determinations including 15 minutes, 30 minutes and one hour. High Pressure Gas Chromatography (HPGC) was employed to determine the quantity of free formaldehyde present in soak water. Water absorption and thickness swelling of the soaked samples were determined using standard methods. Hundred samples each for bending strength (MOR) and modulus elasticity (MOE) for both treated and untreated samples were determined according to Kenya Bureau of Standards KS02-982 Pt.1 (1987). Data obtained was subjected to statistical F-test analysis to determine any significant difference between the various levels of fuming for all the parameters determined in the study using SPSS version 10.1 computer programme. Further, statistical tests were done using Tukey post hoc statistical tests to separate means that were not significantly different in previous tests.

RESULTS AND DISCUSSION

Free formaldehyde quantification

Table 1 shows the quantity of formaldehyde present in cold soaked ammonia treated and untreated samples. Highest formaldehyde level was found in untreated samples, which increased from one to twenty-four hour soaking time. There were significant differences ($P \leq 0.05$) in amount of formaldehyde among untreated samples for 15 and 30 minutes in all the soaking times. But there was no significant difference ($P \leq 0.05$) in amount of formaldehyde in ammonia treated samples for 30 and 60 minutes for all the soaking times. This implied that fuming particleboards beyond 30 minutes would have no effect on quantity of formaldehyde. The appropriate treatment time should be between 15 and 30 minutes. The reduction in formaldehyde released from the samples presumably occurs via the formation of hexamethylene with the free formaldehyde as shown in equation 1 (Chang *et al.* 2002).

$$6CHOH + 4NH_3 \text{ -----------------> } N_4(CH_2)_6 + 6H_2O \text{ -------}$$ (Equation 1)

This reaction may have occurred during the process, thus reducing the amount of formaldehyde determined in the process. Additionally, there may be some neutralisation of the remaining acid cure catalyst, which decreased the production of formaldehyde from hydrolytic reaction. Subsequently, the much stronger hydrogen bonding will undoubtedly create a reservoir of sorbed ammonia within the board that would be available to take up any additional formaldehyde liberated.

Table 1: Quantity of free formaldehyde in cold (23^0C) soaked samples

Soaking time (hrs)	Free formaldehyde (parts per million)			
	Untreated	15 min ammonia fumed	30 min ammonia fumed	60 min ammonia fumed
24	2.289	1.300	0	0
2	0.816	0.451	0	0
1	0.335	0.240	0	0

Table 2 shows the quantity of formaldehyde present in cold soaked ammonia treated and untreated samples. The highest level of formaldehyde was recorded in untreated samples, which was significantly different ($P \leq 0.05$) in all the soaking times. There was a significant difference ($P \leq 0.05$) in amount of formaldehyde in untreated and treated samples for 15 and 30 minutes in all the soaking times. This implied that increasing the temperature from room temperature to 60^{o}C would result into increased formaldehyde emission from the particleboards. It should be noted therefore that high temperatures accelerate free formaldehyde release, thus there is need to maintain low temperatures to ensure low formaldehyde emissions.

Table 2: Quantity of Free-formaldehyde in warm (at 60^{0}C) soaked samples

Soaking time (min)	Free formaldehyde (part per million)			
	Untreated	15 min ammonia fumed	30 min ammonia fumed	60 min ammonia fumed
60	3.338	2.112	0.320	0
30	1.588	0.823	0.230	0
15	1.081	0.432	0.121	0

Particleboards to be used at high temperatures should be ammonia fumed for between 30 minutes and 60 minutes for the safety of the users. The same explanation as above may be true but due to high temperature, more formaldehyde is released to compete with less ammonia ions that have been introduced resulting to high formaldehyde levels obtained unlike the one at low temperatures

Effect of ammonia fuming on thickness swelling

Figure 1(a) shows the effect of different levels of ammonia fuming on thickness swelling at room temperature. Untreated samples showed the highest thickness swelling at room temperature followed by 15, 30 and lastly 60 minutes soaking. The thickness swelling was significantly different ($P \leq 0.05$) among the untreated and treated samples for 15, 30 and 60 minutes. This shows that increasing ammonia fuming reduces thickness swelling. Thus, ammonia fuming has a positive effect as it reduces thickness swelling of particleboards.

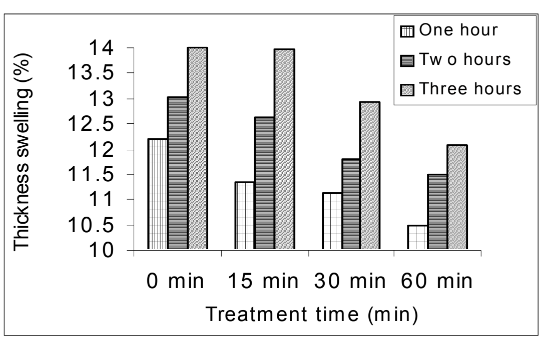
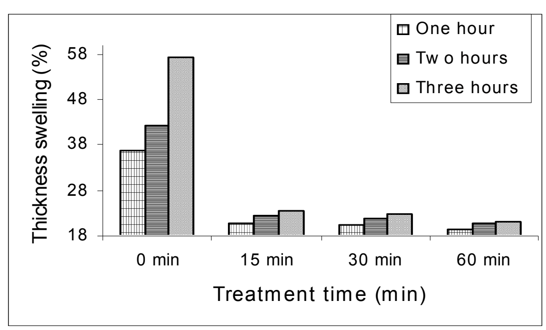


Figure 1 (a): Thickness swelling at room temperature



(b): Thickness swelling at 60^{o}C

Figure 1(b) shows the effect of different levels of ammonia fuming on thickness swelling at 60°C. The highest thickness swelling occurred in untreated samples, followed by 15, 30 and 60 minutes. There was a significant difference (P≤0.05) in thickness swelling between ammonia treated and untreated samples at all soaking times.

However, there was no significant difference (P≤0.05) in thickness swelling between the treated samples at all soaking times. Increasing ammonia fuming time at high temperatures was noted to cause no great effect in thickness swelling. The reduction in thickness swelling in both cases could be due to the reduction of hygroscopicity of the wood molecules.

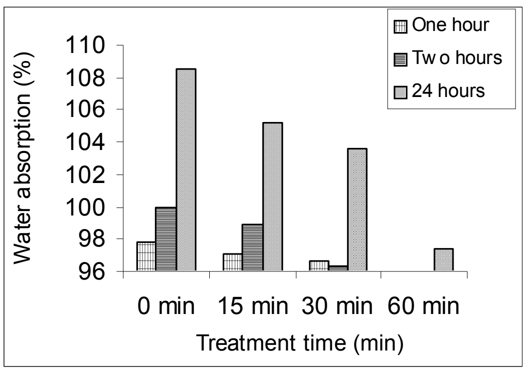


Figure 2 (a): Water absorption at room temperature

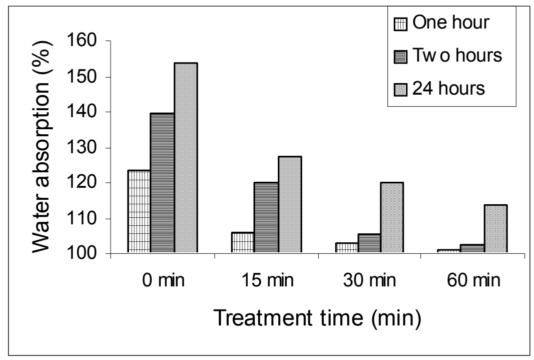


Figure 2 (b): Water absorption at 60°C

Effect of ammonia fuming on water absorption

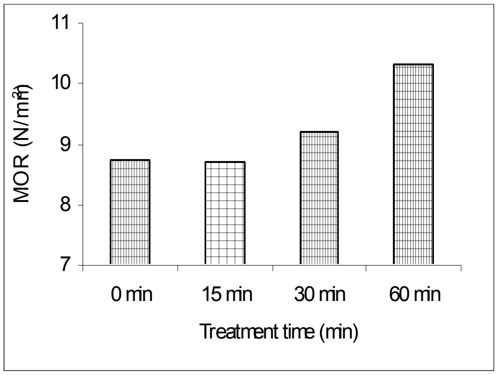
Figure 2(a) shows the effect of different levels of ammonia fuming on water absorption at room temperature. High water absorption was recorded in untreated samples, which was significantly different (P≤0.05) from all the levels of ammonia treatment at all soaking times. There was also a significant difference (P≤0.05) in water absorption among the treatment times in all the soaking times. This indicates that increasing ammonia-fuming time would therefore reduce water absorption at room temperature.

Figure 2(b) shows the effect of different levels of ammonia fuming on water absorption at 60°C. Highest water absorption occurred in untreated samples, which reduced as the time of ammonia fuming increased from 15 minutes to 60 minutes. There was a significant difference (P≤0.05) in water absorption within the untreated and between treated and untreated samples. However, there was no significant difference (P≤0.05) in water absorption between the treated samples for 15 and 60 minutes for all the soaked samples except the ones soaked for 60 minutes. Reduction in water absorption could be due to the formation of less hygroscopic molecules resulting to less up take of water.

Moduli of rigidity and elasticity

Figure 3(a) shows the effect of different levels of ammonia fuming on modulus of rigidity. MOR increased with increase in ammonia treatment time, from 15 to 60 minutes. There was a significant difference (P≤0.05) in moduli of rigidity and elasticity between the treated and untreated samples for 30 and 60 minutes. This implies that increasing ammonia fuming time increases MOR of particleboards, which is a positive effect. However, it was noted that there was no significant difference ($P \leq 0.05$) in moduli of rigidity and elasticity between untreated and treated samples for 15 minutes.

Figure 3(b) shows the effect of different levels of ammonia fuming on modulus of elasticity. MOE increased as time of treatment increased from 15 to 60 minutes. However, the rate of MOE was noted reduced as treatment time increased. There was a significant difference ($P \leq 0.05$) in moduli of rigidity and elasticity between untreated and all levels treated samples.



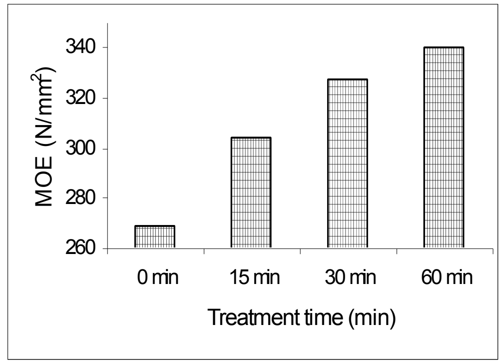


Figure 3 (a): Effect of ammonia fuming on MOR

Figure 3 (b): Effect of ammonia fuming on MOE

CONCLUSIONS AND RECOMMENDATIONS

Fuming particleboards with ammonia reduces the amount of free formaldehyde emission. It reduces totally free formaldehyde present and any reservoir of ammonia would continue to reduce any liberation thereafter. Ammonia fuming could be done at plant condition without any special process requirement. The fuming reduced thickness swelling by between 14.1 and 11.5% and water absorption on average from 98.6 to 90.5%. It also increased modulus of rigidity of the particleboards on average by 26.6% after total formaldehyde removal, and MOE of the particleboards on average by 10.6% after total formaldehyde reduction.

It is therefore recommended that to reduce formaldehyde emissions, factories should adopt ammonia fuming of the particleboards. This would protect the health of the product's users. It is further recommended that studies be carried out to determine the long-term effect of ammonia fuming on particleboards.

REFERENCES

Brown, S. K., 1999. Chamber Assessment of Formaldehyde and VOC Emissions from Wood-Based Panels. Journal of Indoor Air, September 1999, Vol. 9 Issue 3, p209.

Chang, J. C. S., Guo, Z., Fortmann, R., Lao, H.C., 2002. Characterization and Reduction of Formaldehyde Emissions from a Low-VOC Latex Paint.. Journal of Indoor Air, March 2002, Vol. 12 Issue 1, p10-15

Environmental Protection Agency (1991) Sources of Indoor Air Pollution – Formaldehyde. State of California Air Resource Board, No. 1, September 1991.

George, E. M., 1982. Formaldehyde-dynamics Air Contamination by Hardwoods Plywood Boards Treatment, Forest Product Journal, Vol. 32 No. 4. John Willey and Sons Ltd.

George, E. M., 1986 Effects of Post-manufacture Boards Treatment on Formaldehyde Emissions: A

Literature Review (1960-1984). Forest Product Journal, Vol. 36 No. 6. John Willey and Sons Ltd.

George, E. M., 1981. Investigation of Urea-formaldehyde Polymer Cure by Infrared, Forest Product Journal, Vol. 19 No. 2. John Willey and Sons Ltd.

George, E. M., 1984. How Mole Ratio of UF Resins Affects Formaldehyde Emissions and Other Properties: A Literature Critique. Forest Product Journal, Vol. 34 No. 5. John Willey and Sons Ltd.

GOK 1987. Kenya Standard Methods of Test for Determination of Physical and Mechanical Properties of Wood, Government Printer, Nairobi Kenya.

Keil, C. B., Akbar-Khanzadeh, Konecny, F., and Kelly A., 2001. Characterizing Formaldehyde Emission Rates in a Gross Anatomy Laboratory. Applied Occupational & Environmental Hygiene, October 2001, Vol. 16 Issue 10, p. 967-972

Lawrence, G., and Wellons, J. D., 1979. Analytical Methods for Formaldehyde. Forest Product Journal, Vol. 22 No. 6. John Willey and Sons Ltd.

Nevers, S., and Lehmann, T., 1968. Triethymine Stabiliser of Resin in Douglas-fir Particleboards, Forest Product Journal, Vol. 28 No. 12. John Willey and Sons Ltd.

Risholm-Sundman, M., 1999. Determination of Formaldehyde Emission with Field and Laboratory Emission Cell (FLEC)--Recovery and Correlation to the Chamber Method. Journal of Indoor Air, December 1999, Vol. 9 Issue 4, p268-272

Sherman, M., and Hodgson, A. T., 2004. Formaldehyde as a basis for residential ventilation rates. Journal of Indoor Air, February 2004, Vol. 14 Issue 1, p2, 7p.

State of California Air Resources Board 1991. Formaldehyde in the Home In Indoor Air Quality Guideline, Vol. 1 September 1991.

State of California Air Resources Board (1991). Indoor Emissions of Formaldehyde and Toluene Diisocyanate: In Indoor Air Quality Guideline, Vol. 1 September 1991.

Semra, Ç., Ismail, A., Cenk, D., and Gürsel Ç., 2004. Some Technological Properties of Laminated Veneer Lumber Manufactured from Pine (*Pinussylvestris* L.) Veneers with Melamine Added - UF Resins. Turk J Agric 28 (2004) 109-113

Nathalie, H. G., Robert, C., Brunet, and Gaetan, C., (2003). Comparative Occupational Exposures to Formaldehyde Released from Inhaled Wood Product Dusts versus that in Vapor Form. Journal of Applied Occupational and Environmental Hygiene, Volume 18(5): 384–393, 2003.