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The Effects of Flame Retardants on Combustion of Some Tropical Woods

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Abstract
Penta-erythritol, melamine and diammonium hydrogen orthophosphate were doped into emulsion paint and painted into some tropical woods that are commonly used for building, furniture, and other construction. These woods are *Daniellia oliveri*, *Anogeissus leiocarpa*, *Mansonia altissima* and *Vitex doniana*. The woods were also doped with a combination of urea fertilizer and alum dissolved in water. Paint formulations were prepared by using a combination of penta-erythritol, melamine and diammonium hydrogen orthophosphate and alone with gypsum. Some woods were painted with the formulations. The flame retardation effects of each of these formulations on the combustion of these tropical woods were determined through the following combustion parameters; ignition time, flame time, after glow, char length, flame propagation rate, moisture content and percent add-on. It was observed that the flame retardants really had retardation effect on the combustion of these tropical woods. The order of the degree of their retardation effects, a combination of urea fertilizer and alum is the highest, followed by paint mixed with gypsum and lastly, paint doped with penta-erythritol, melamine and diammonium hydrogen orthophosphate.
Keywords: Flame retardants, wood, combustion, paint, perservatives

1.0 Introduction

Wood is one of the most worthy and widely used natural resources for many uses such as furniture and construction. It is chemically made up of 60% cellulose, 28% lignin and 12% sugar and extractives. The challenges posed by environmental pollution due to the volume of wastes generated by non degradable materials have renewed interest in materials such as wood. Research interest has centered on how to improve the durability and reduced flammability (Ostman *et. al*., 2001 and Ozdemir and Tutus, 2013) of wood through the application of preservatives (Jiang *et. al*., 2010). However, several wood species are resistant to impregnation due their structure. In order to overcome issues related to low impregnability of different wood species a passive impregnation method was developed, whereby no direct pressure is applied to impregnate preservative into wood (Hattori *et. al*., 2005). Flame retardant is a compound or mixture of compounds which when added to or chemically incorporated into a polymer it substantially suppresses the ease of flame ignition and propagation. Different chemicals have been used as fire retardants when applied to many varieties of wood (Simkovic *et. al*., 2007 and Baysal *et. al*., 2007) whereas, heat treatment has been shown to improve the physical and mechanical properties of wood and wood products so that they can be used more effectively during their service life (Bakar *et al.,* 2013; Kasemseri *et al*., 2012; Dilik and Hiziroglu, 2012). In order to reduce the number of occurrence of fire accidents both domestically and industrially, the flammability nature of wooden materials must be controlled by being impregnated with flame retardants (Islam, 2013). The purpose of the research work is to determine an effective flame retardant that can be used for the control of the ignitability and the combustibility of some tropical woods commonly used for building and furniture constructions

2.0 Materials and Methods

2.1 Sample Collection

The four species of tropical woods (*Daniellia oliveri*, *Anogeissus leiocarpa*, *Mansonia altissima*, and *Vitex doniana*) that were used during the research work were obtained from Jos Katako timber market. For convenience, these woods shall now hence forth be addressed as *Daniellia*, *Anogeissus*, *Mansonia* and *Vitex*. The flame retardants that were used for the work are as follows: Penta-erythritol – obtained from BDH Chemicals Limited,

Melamine - obtained from BDH Chemicals Limited, Diammonium hydrogen orthophosphate– BDH Chemicals Limited, Emulsion paint – Herbertex Limited,Urea Fertilizer – NAFCON, Port-Harcourt and Alum – bought from the market.

2.2 Sample Preparation

The samples of each wood species were first air dried several weeks, cut and machines into splints of dimensions 150 x 15 x 10 mm. Four wood samples from each species were treated with each of the following retardant formulations.

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(i) The retardants: melamine, penta-erythritol and diammonium hydrogen orthophosphate were mixed (3:1:1 w/w respectively) prepared into slurry and doped into 50m/s of emulsion paint. The mixed flame retardants were prepared into five different concentrations from 5-25 g range. The sixty concentrations were prepared only with emulsion paint as the control. Four wood samples from each species were treated with each formulation. The specimens were air dried and conditioned for three days in the laboratory before testing.

(ii) 50 ml each of emulsion paint was doped with five different concentrations (5-25 kg) of gypsum. The sixth concentration was prepared at zero concentration as the control. Four wood samples from each species were impregnated with each formulation; air dried and was conditioned in the laboratory for three days before the test.

(iii) Urea fertilizer and alum were mixed (1:1 w/w) and prepared into five different concentrations as from 50-250 g/dm^3). The sixth concentration was left without treatment. Four wood samples of each species were soaked in each retardants solution for 24 hours. The samples were air dried for three days, cured at ……. For 10 minutes and reconditioned again for three days before testing.

2.3 Flame test

A sample was vertically clamped and ignited at the bottom with a candle lighter. The ignition time and the transverse distance in the vertical direction by the char from and the time taken were also noted.

2.4 Flame Propagation

The samples were clamped vertically and then ignited at the base in a drought –free room using a candle. The distance travelled at a stipulated time interval by the char front was measured and the rate of flame propagation was calculated as the vertical distance transverse per second (Ike, 2011).

$$\text{Flame propagation rate, } v(mms^{-1}) = \frac{\text{Distance moved by char front (mm)}}{\text{Time (s)}}$$

2.5 Afterglow Time

This was measured by recording the time between flame out and the last visually perceptible glow (Ike, 2011). Afterglow = time taken between flame out and last visually perceptible glow(s)

2.6 Ignition Time

The samples were clamped vertically at the distance of 5.00cm from the surface of a candle burner which was adjusted to give a steady flame. The ignition time was determined by noting the time (second) from when ignition flame was applied and removed after the specimen exhibited a self sustaining flame (Ike, 2011).

2.7 Char Front

This was determined by measuring with a rule the transverse distance vertically advanced by the flame. This is expressed in millimeter (mm) (Jauro, 1999).

$$\text{Char } (^\circ/_\circ) = \frac{\text{Weight of material after burning}}{\text{Weight of material before burning}} \times 100$$

2.8 Percent Moisture

This was determined during sample preparation whereby the sample was oven dried at 120±30c for 6-8 hours until a constant weight is attained. The loss in weight was expressed as a percentage (Jauro, 1999)

$$\text{Moisture content } (\%) = \frac{Wa - Wo}{Wo} \times 100$$

Where, Wa = condition weight

Wo = oven dried weight of the respective sample.

2.8 Percentage Add-On

Woods were prepared variable amount of flame retardants added in situ and wood samples without flame retardants. Rectangular shaped wood materials were cut from treated and untreated wood with known dimensions. The weight of the wood with flame retardant (W_a) minus the weight of the wood without flame retardant (W_b) divided by the weight of wood without flame retardant multiplied by100 (Ike, 2011)

Add-On ($^\circ/_\circ$) = Wa-Wb x100

3.0 Results and Discussions

Flame retardant effects of paint doped with pentaerythritol, melamine, and diammonium hydrogen orthophosphate on ignition time, flame time, after glow, char length and propagation rate is given in figures 1to5 respectively.

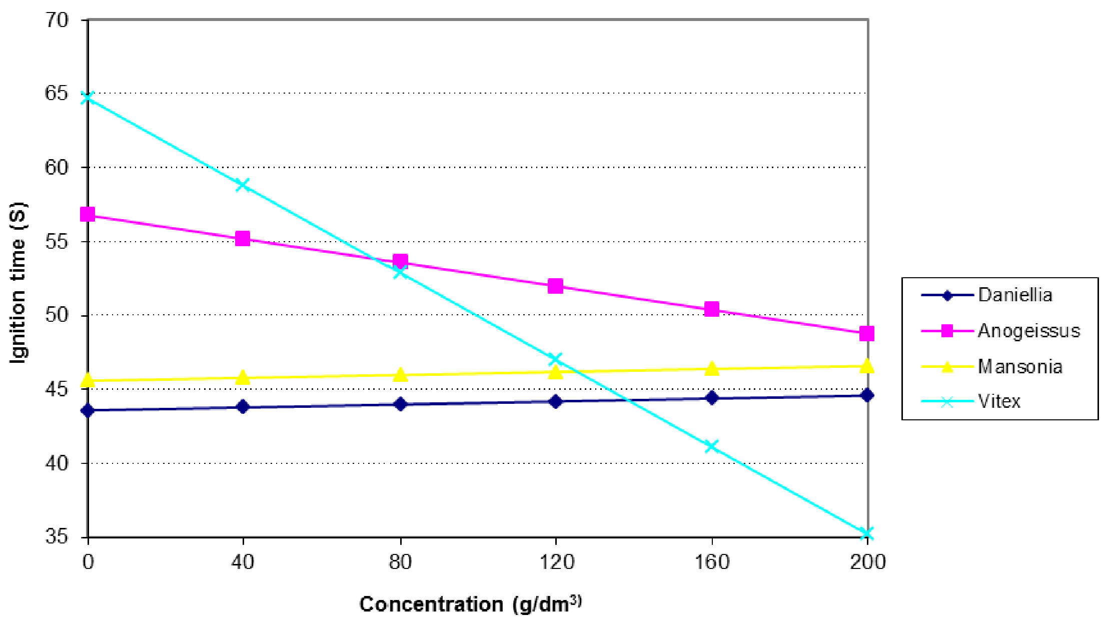


Fig. 1: Effect of a paint doped with Pentaerythritol, Melamine and Diammonium hydrogen orthophosphate on Ignition time.

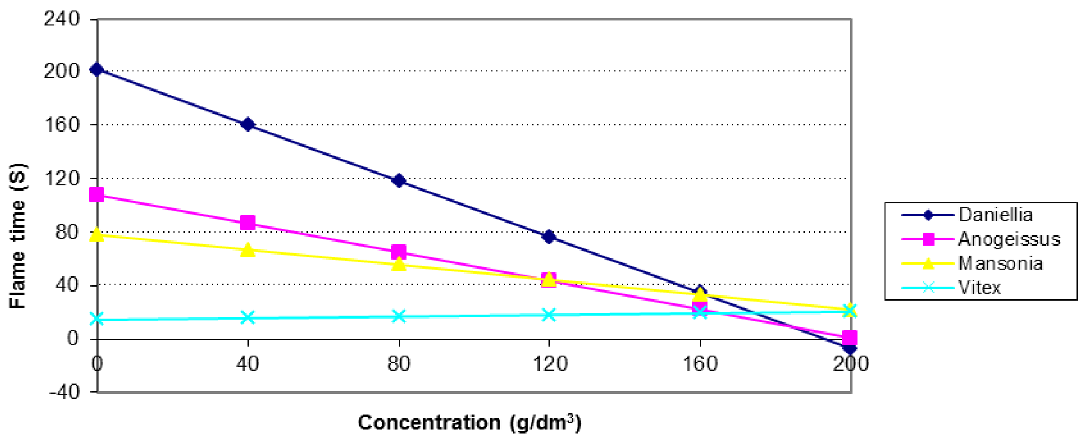


Fig 2: Effect of a paint doped with Pentaerythritol, Melamine and Diammonium hydrogen orthophosphate on Flame time

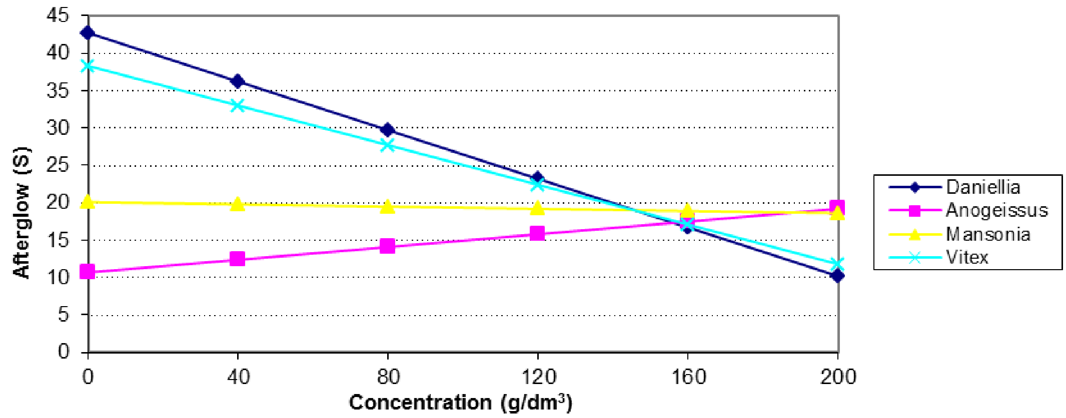


Fig 3: Effect of a paint doped with Pentaerythritol, Melamine and Diammonium hydrogen orthophosphate on Afterglow

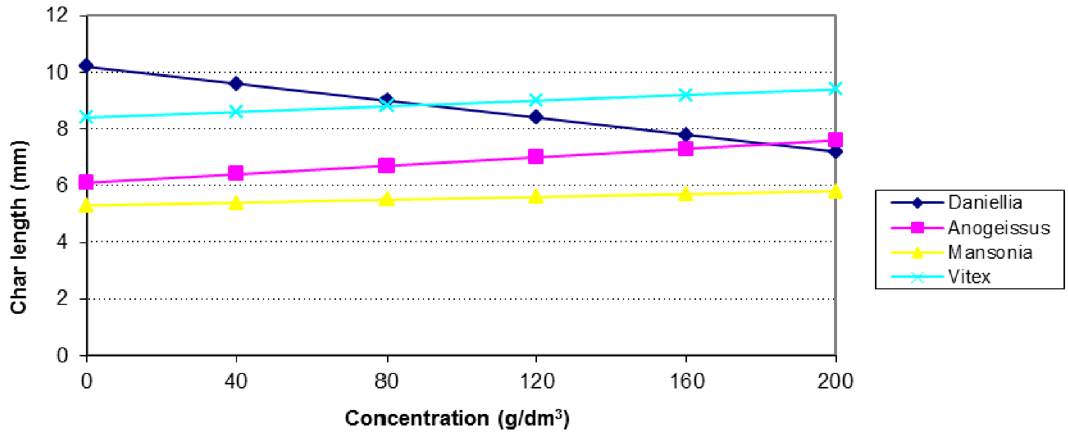


Fig 4: Effect of a paint doped with Pentaerythritol, Melamine and Diammonium hydrogen orthophosphate on Char Length

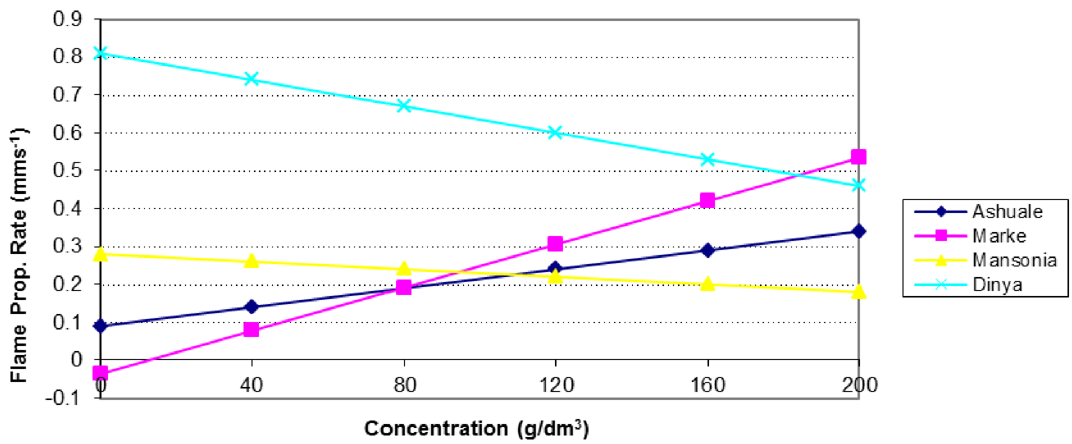


Fig 5: Effect of a paint doped with Pentaerythritol, Melamine and Diammonium hydrogen orthophosphate on Flame Propagation Rate

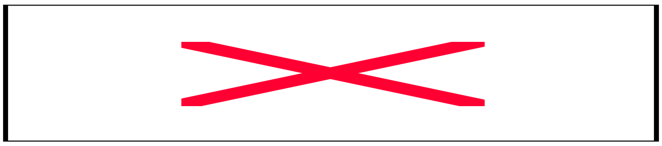
Effects of paint doped with Pentaerythritol, melamine and diammonium hydrogen orthophosphate on wood combustion. It is observed that with an increase in concentration there is decrease in ignition time, flame time and afterglow. While half of the samples show an increase and decrease in char length and flame propagation rate with increase in concentration. The results obtained are similar to what was obtained by Momoh *et. al.*, (1996).

Penta-erythritol and melamine as intumescent systems were noted to control the flammability of woods and other cellulosic like fabrics, polyvinylchloride, and engineering thermoplastics

-2EtCl $\longrightarrow$ -4EtCl

$2(Eto)_3 P(O) + CH_3CCl_3 \longrightarrow (Eto)_2P(O)C(CH_3)(Cl)P(O)(Oet)_2 + HCl$

$(OH)_2 P(O) C(CH_3)(Cl) P(O) (OH)_2$ + Melamine $\longrightarrow$ melamine.$(OH)_2 P(O) C(CH_3)(OH) P(O)(OH)_2$ Melamine(DFM). White diammonium hydrogen orthophosphate reduces the



combustibility (Islam, 2011; Bayal *et. al*., 2002) of woods and other cellulosic through chemical treatment, cross linking reaction, grafting by chemical treatments (Ayrilmus, 2005).

Where x = 4 A = 20N H4, IOH and 1NH2. The treatment confers excellent fire resistance with only 5% loss of strength and fair resistance to hot laundering. Paint doped with penta-erythritol, melamine and diammonium hydrogen orthophosphate from the result obtained is the third most effective flame retardant.

Figures 6 to 10 show the effects of paint mixed with gypsum on ignition time, flame time, after glow, char length and propagation time respectively. It was noted that with an increase in concentration of the flame retardant, there is increase in ignition time, flame time and char length, whereas some of the samples showed decrease in afterglow and flame propagation rate with increase in concentration. The results showed that paint mixed with gypsum is the second most effective in retarding the flammability of some tropical woods. This finding is similar to what was obtained by other workers who did similar work.

This is not surprising because gypsum is a hydrated calcium sulphate ($CaSO_4$). Some of the heat supplied would be used in deriving the water of hydration. The calcium sulphate itself is stable to high temperatures and is a good heat reflector. These properties are responsible for the flame retardation effect.

Gypsum $\longrightarrow CaSO_4 \; x \; H_2O$

Effects of a mixture of urea fertilizer and alum on wood ignition time flame time, after glow, char length and propagation time is shown in figures 11 to 15 respectively. These results showed that with an increase in concentration, a decrease in flame time, char length and flame propagation rate was observed. But some samples showed that an increase in ignition time, half of the sample showed increase and half also showed decrease in afterglow with an increase in concentration. Also observed with increase in concentration from the minimum value of 25 g/dm^3 to an optimum value of 75 g/dm^3 is an increase in percent add-on. While percent add-on decreased with increase beyond the optimum concentration value. The increase in percent add-on probably could be due to movement of molecules from the region of higher concentration (solute solution) to a region of lower concentration (wood cell) by a semi permeable membrane (diffusion). But the decrease in percent add-on is as a result of osmosis that involves movement of molecules from the region of lower concentration (wood cell) to a region of higher concentration (solute solution).

The results showed that a mixture of urea fertilizer and alum produced an excellent fire resistance on the treated wood samples. It was observed that a mixture of urea fertilizer and alum became the first most effective flame retardant. This is because urea when decomposed, releases two non-combustible gases, NH_3 and CO_2. The combined effect of the gases suffocates the flame.

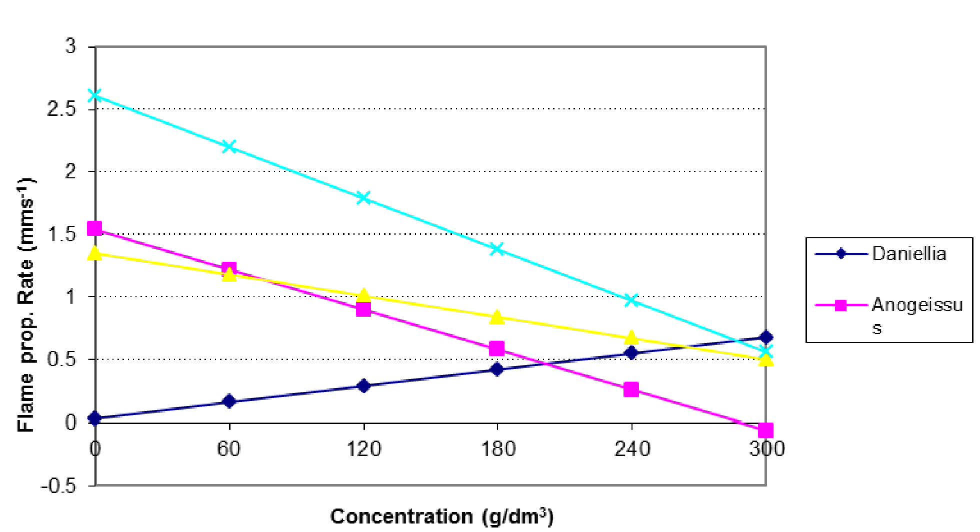


Fig 10: Effect of paint mixed with Gypsum on Flame Propagation time

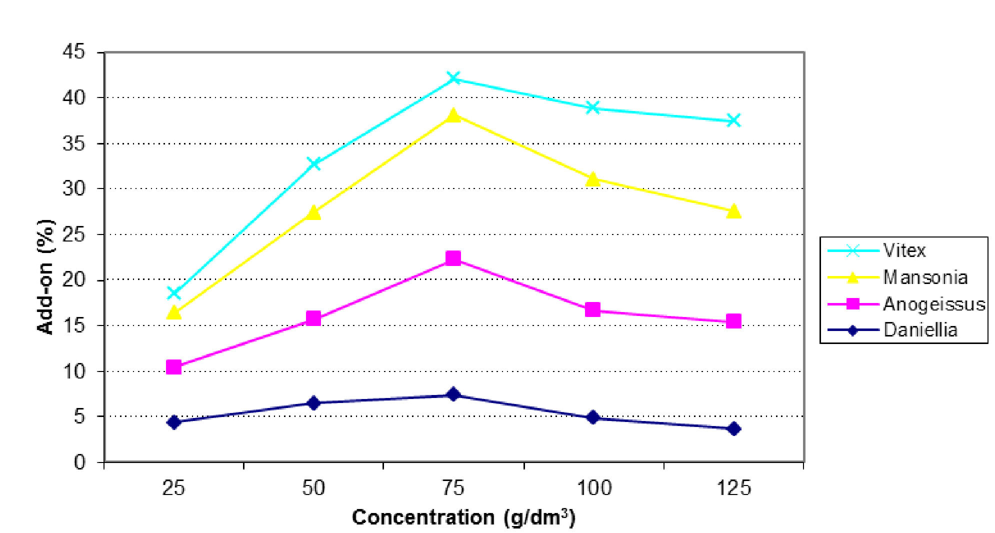


Fig 11: Effect of a mixture of Urea and Alum on % Add-On .

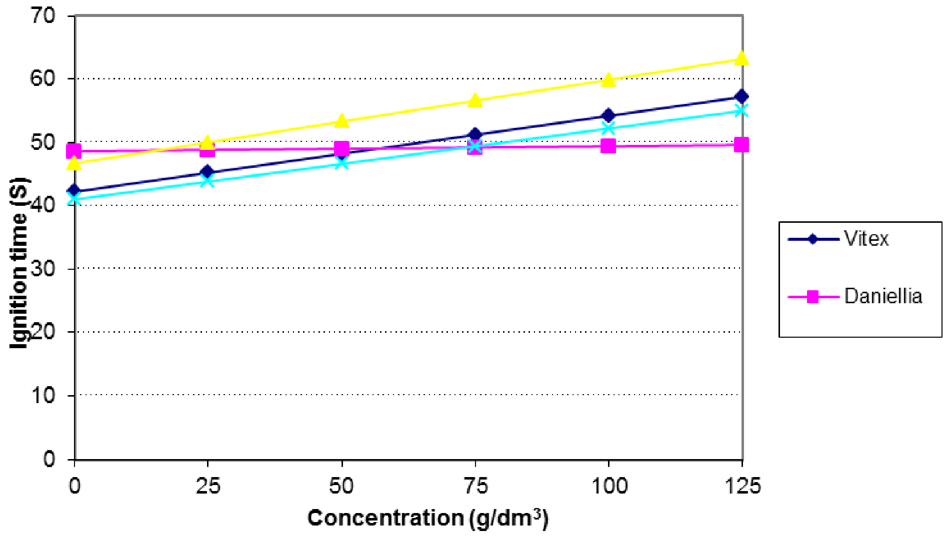


Fig. 12: Effect of a mixture of Urea and Alum on Ignition Time

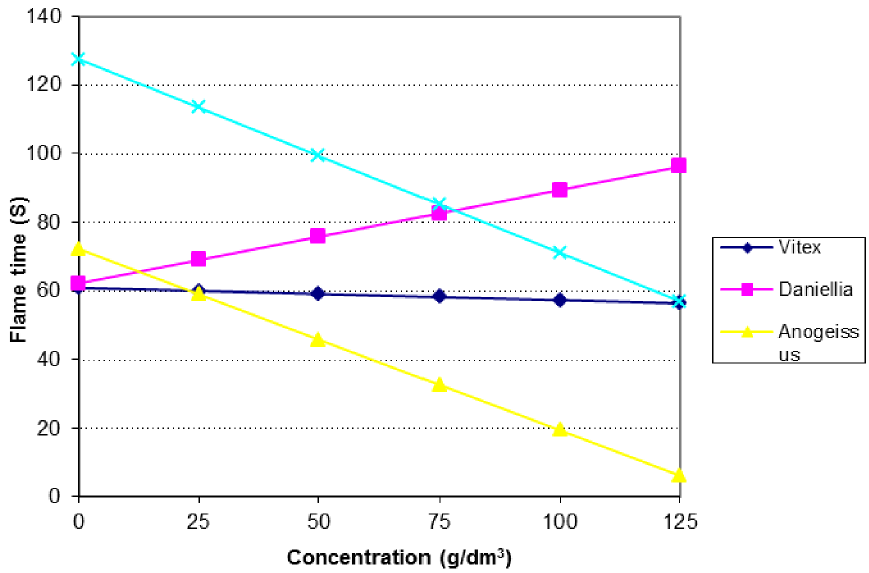


Fig. 13: Effect of a mixture of Urea and Alum on Flame Time

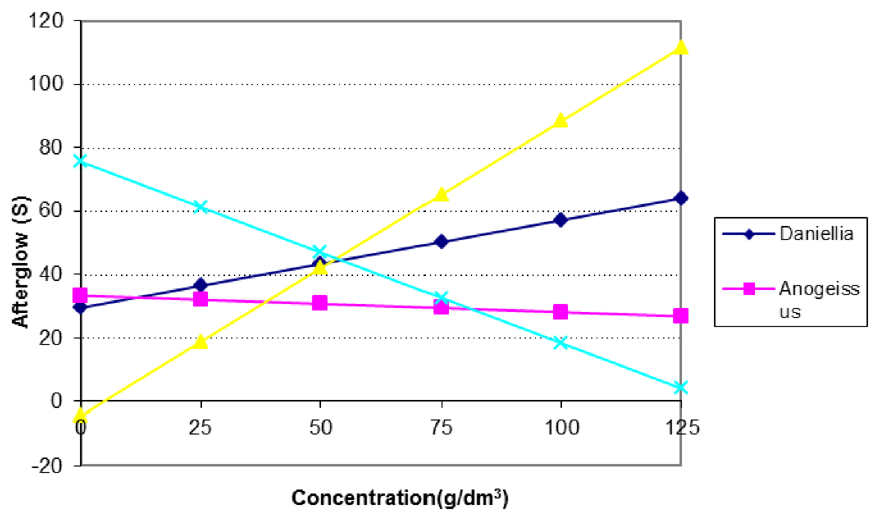


Fig. 14: Effect of a mixture of Urea and Alum on Afterglow

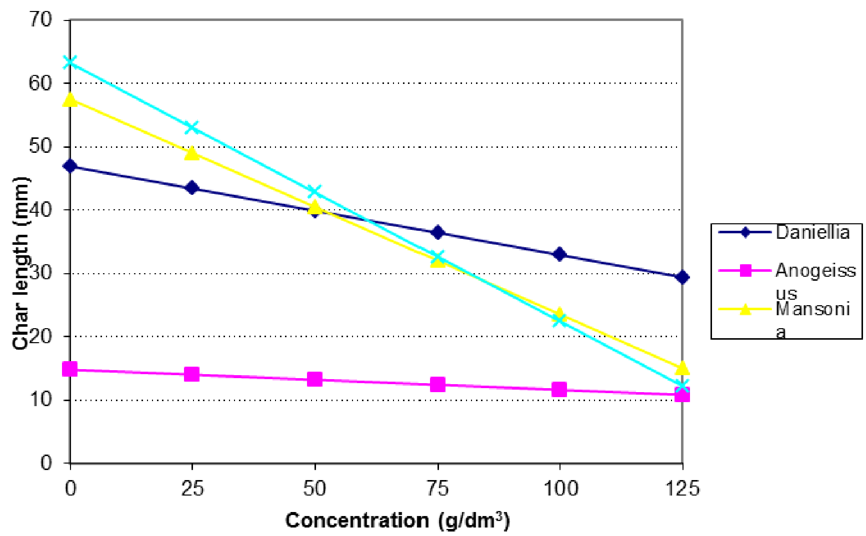


Fig. 15: Effect of a mixture of Urea and Alum on Char Length

4.0 Conclusions

The effects of flame retardants on the combustion of some tropical woods have been successfully studied. The results obtained showed that a combination of urea fertilizer and alum is the most effective flame retardant. The next formulation following in performance is paint mixed with gypsum and lastly, paint doped with penta-erythritol, melamine and diammonium hydrogen orthophosphate respectively.

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