Synergistic Study on the Effect of Flame Retardants on Timber

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ABSTRACT:- *the fire characteristic proportion of Halleacilliata has been carried out. The timber was treated with different concentrations of ammonium chloride (0.01, 0.05, 0.10, 0.15, 0.50, and 0.55) mol/dm^3 and borax (0.01, 0.03, 0.05, 0.07, 0.10, and 0.12) mol/dm^3. Flammability tests such as ignition time, flame propagation rate and after-glow time were carried out and the results showed that the flame retardants drastically reduced the flame propagation rate and after-glow time while ignition time and percentage add-on (%) increased. Synergy was observed when the two flame retardants were mixed at different concentrations which gave better retarding properties than when treated individually. These results are interpreted as arising from the fact that on heating, these flame retardants evolve molecules that interfere with the chemistry and pyrolysis of combustion of timber.*
Keywords: *-combustion, synergy, flame retardant, Timber*

I.　　INTRODUCTION

The utility of timbers in various applications is as a result of its indispensable properties that give good aesthetics and structural design. Wood is a renewable, sustainable and easily workable material that has been used in building industry for thousands of years. Its use remains wide spread ranging from structural frames to floors, paneling, doors, interior and exterior wood work and furniture [1]. However, the deficiency of this polymeric material in the presence of heat has made it more vulnerable to destruction. This has engulf lives, properties, damages and will still do more if precautionary measures are not implemented. The method by which the flammability of polymers e.g. textile, roughing thatch,foam etc. can be reduced by chemical means has been extensively investigated and documented [2-4]. In this paper we reported the synergism using ammonium chloride (NH_4Cl) and borax ($Na_2B_4O_7.10H_2O$) on the flame characteristics of timber known as Halleaciliata.

II.　　EXPERIMENTAL

2.1 Materials

The timber studied is *Halleaciliata*which is referred by its local names as 'owen' or 'abura'. Ammonium chloride (NH_4Cl) was procured from BDH Laboratory Supplies Poole, BH151 TD, England and assay as: ex. Cl (98%), SO_4 (0.01%) and Fe (0.05%): disodium tetraboratedecahydrate or borax ($Na_2B_4O_7.10H_2O$) procured from BDH Laboratory poole and essay as: Pb (0.001%), Cu (0.001%), Fe (0.0003%), Ca (0.005%), PO_4 (0.002%), SO_4 (0.01%), Cl (0.002%). All chemicals were used as supplied by the manufacturers.

2.2Method

(a) Preparation of material: the timber was sized, cut into wood splints to the length of 30cm, width of 0.5cm, breadth 0.5cm and subjected to further analysis.
Flame-retardant treatment: The timber was dried in the electric oven at 105-110°C to constant weight using weighing balance. Weight of the dry sample were completely immersed in equal volumes but different concentration of flame retardants contained in 1000cm^3 measuring cylinder for a resident time of 48hrs. On removal from the dope, the sample was dried again to relative constant weight in the electric oven (105-110°C). The weight of flame-retardant absorbed by sample was determined, using the expression [5]:

$$\text{Add-on(\%)} = \frac{[Y - X]}{X} * \frac{100}{1}$$

Where Y= weight of the sample after treatment.

X= weight of the sample before treatment.

(b) Combination treatment: Equal volumes (500cm^3) of each of the prepared flame retardant solutions was mixed and impregnated into the wood splint for 48hrs and dried at the temperature 105-110°C to constant weight using weighing balance.

The individual and combined effect was compared using the expression [6]:

Neilson's additivity equation:Theoretical = observed * mole fraction

$$\left[F_{a1} * \frac{a}{(a+b)} \right] + \left[F_{b1} * \frac{b}{(a+b)} \right]$$

Where a= concentration of ammonium chloride

b= concentration of borax

F= observed values

(c) Determination of ignition time (IT): the sample was clamped vertically by its upper end and ignited at the base with a cigarette lighter having a constant flame height and a constant distance (i.e. 4cm apart) between its lower tip and small cigarette lighter. Ignition time was recorded as the time interval between the lighter touching wood tip and a tiny visually perceptible flame on the sample[7]. Three readings per sample were taken and the average calculated.

(d) Determination of flame propagation rate [F.P.R]: the flame propagation rate was determined by clamping vertically the sample and igniting at the base in a drought-free room. The distance travelled at a stipulated time interval by the char-front was measured and the average readings were recorded [7].

The rate of propagation was calculated as the distance transverse per second.

Flame propagation rate (cm/s) = [distance moved by char-front (cm)]/ [time(s)]

(e) Determination of after-glow time: this was taken as the time between flame-out and the last visually perceptible glow [7]. The test was carried out for three times and the average was recorded for accuracy.

III.   RESULTS AND DISCUSSION

*Table I: fire characteristics of the treated timber*

Conc (Mol/dm^3)	Ammonium chloride NH$_4$Cl				Conc (Mol/dm^3)	Borax or disodium teraboratedecahydrate Na$_2$B$_4$O$_7$.10H$_2$O				Conc (Mol/dm^3)	Combined (NH$_4$Cl+ Na$_2$B$_4$O$_7$.10H$_2$O)			
	Add-on (%)	IT (s)	F.P.R cm/s 10^-1	A.G. T (s)		Add-on (%)	IT (s)	F.P.R cm/s 10^-1	A.G. T (s)		Add-on (%)	IT (s)	F.P.R cm/s 10^-1	A.G. T (s)
0.00	0.00	5.78	3.57	301.19	0.00	0.00	5.78	3.55	301.20	0.00	0.00	5.78	3.58	301.21
0.01	0.36	8.78	3.06	95.20	0.01	2.08	6.59	2.73	217.32	0.01	0.44	19.38	1.23	282.91
0.05	0.47	10.90	2.16	5.00	0.03	6.59	8.99	2.35	206.54	0.04	0.81	19.90	1.01	201.93
0.10	1.57	15.46	1.79	2.93	0.05	6.81	9.49	1.68	167.92	0.08	0.61	24.31	1.04	198.39
0.15	1.45	16.41	1.56	2.07	0.07	6.81	11.82	2.25	135.82	0.11	0.97	27.39	0.67	2.18
0.50	2.35	21.29	2.11	0.98	0.10	7.38	12.98	1.46	125.25	0.30	2.53	29.62	0.94	0.98
0.55	4.37	24.09	1.41	0.11	0.12	7.78	15.16	1.35	100.96	0.34	2.84	31.66	0.21	0.07

The result of the percentage add-on of the flame-retardants is shown in Fig. 1. It is evident that the quantity of flame retardant absorbed by the wood depends on the liquor concentration. In the type of system, i.epolymerics, including cellulosics, the manner of chemisorption is well represented by the Fick's laws. The fick's first law is: J= D [(dc) / (dx)], where J= rate of accumulation of the reagent per unit area of the reference plane orientated normal to the x-axis, D= diffusion coefficient and c= local reagent concentration at a point distance x from the origin of coordinates. A second differential of the first law expression with respect to time is the Fick's second law: [(dj) / (dt)] = D[(d^{2}c)/ (dx^2)]; which implies that the rate of accumulation of the reagent to the surface and hence its penetration into the wood matrix would essentially be linked to the bath concentration [8]. On the basis of this fact the observation highlighted in Fig.1 is in accord with theoretical considerations.

It is observed [Fig.2] that these flame retardants delays ignition with respect to increase in concentration.

The systematic reduction [Table1] in the flame propagation rate [Fig.3] and After-glow time [Fig.4] with the flame retardant treatment is as follows:

Disodium tetraboratedecahydrate (borax): At high temperatures, it decomposes according to the equation:

$$2Na_2B_4O_7.10H_2O_{(s)} = 4NaBO_{2(s)} + 2B_2O_{3(s)} + 10H_2O_{(g)} \quad ------------(1)$$
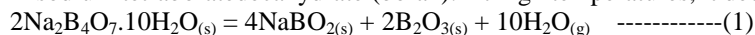
Ammonium chloride: appears to sublime upon heating. However, this process is actually decomposition into ammonia and hydrogen chloride gas.

$$NH_4Cl \rightarrow NH_3 + HCl------------------(2)$$

$$HCl \rightarrow H^. + Cl^.-------------------(3)$$
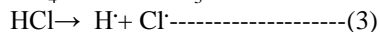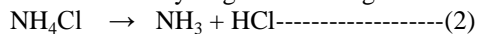
The flame inhibiting property of disodium tetraboratedecahydrate and ammonium chloride are interpreted in terms of vapour and liquid mechanism as the case may be. In the case of borax when heated these formulations decompose to form glass-like coating around cellulosic fibres. Long time exposure to heat causes the coating to dehydrate, generating water. The boron residues also react with the hydroxyl groups of cellulose to generate additional quantities of water and to form difficulty ignitable char. The evolution of water cools the flame as well as dilutes the concentration of flammable pyrolysis products. The glassy coatings not only deflects heat away from the substance but also diminishes aggress of combustible volatile pyrolysates into the combustion zone [9].

The free radicals $H^.$ and $Cl^.$ have the ability to scavenge the $^.OH$ and $^.O$ radicals that are essential for the sustenance of combustion. The gaseous products NH_3 and HCl contribute as diluents of the pyrolysate concentration.

From figs 2-4, synergy is observed from the graph, with the experimental value (observed) greater than the theoretical value. In figs 4, there is more decrease of after-glow theoretically at lower concentration but as it tends to higher concentration, the effect of synergy emerges with more decreasing observed after-glow. This can be due to the factors that affect the anisotropy of wood which is the arrangement and orientation of the wall materials in the cell making up the woody tissue, the kind, size, proportions and arrangement of the cells making up the woody tissue and thermal conductivity of wood which is depends on direction of heat flow with respect to the grain orientation in the wood, moisture content of wood and specific gravity of the wood [10].
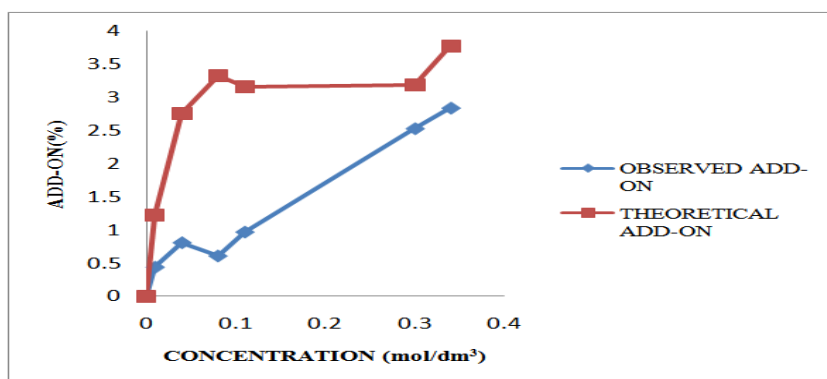

Figure 1: The observed and theoretical effect of concentration of flame-retardants on Add-on
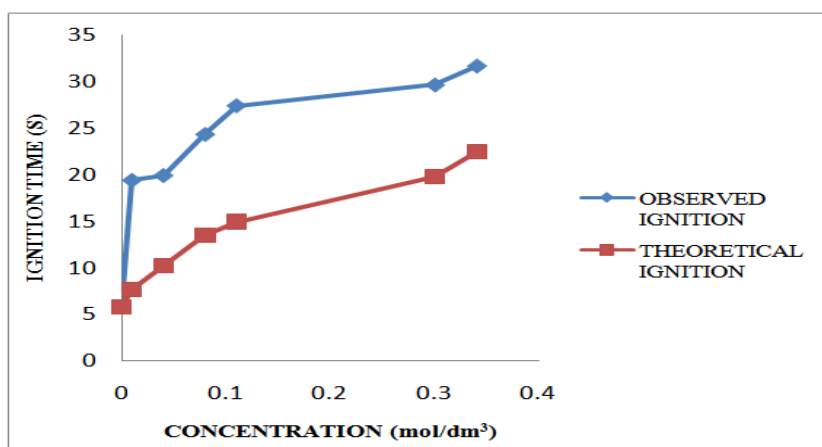

Figure 2: The observed and theoretical effect of concentration of flame-retardants on I.T
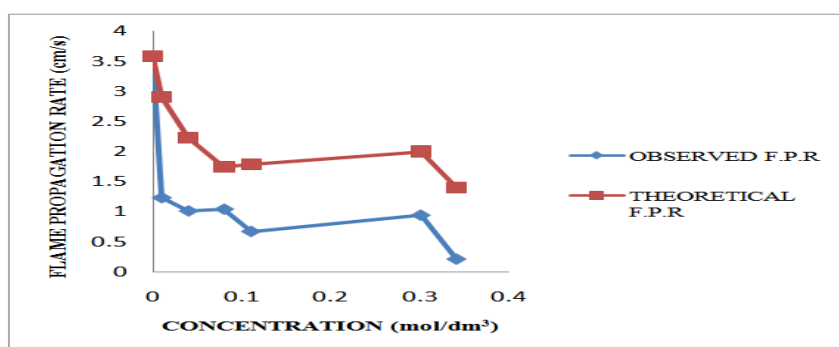
Figure 3: The observed and theoretical effect of concentration of flame-retardants on F.P.R
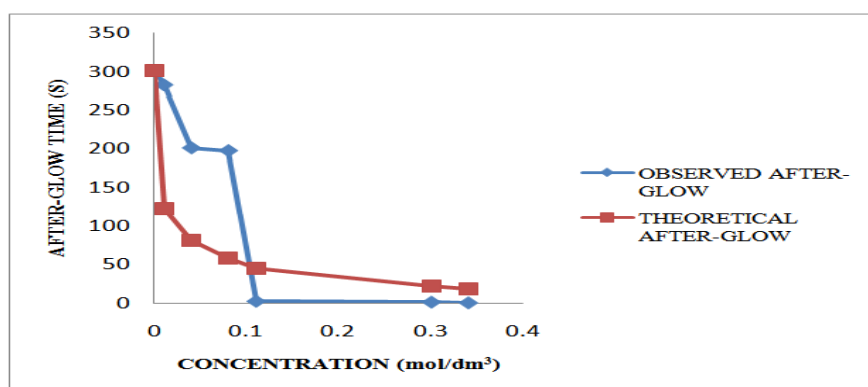

Figure 4: The observed and theoretical effect of concentration of flame-retardants on A.G.T

IV.   CONCLUSION

It is concluded from this investigation that ammonium chloride and borax function as good fire-retardants in delaying and resisting ignition,flame propagation rate and after-glow time, though there was remarkable improvement when the wood was treated individually with each of the flame retardants but it was more pronounced when the two flame retardants was combined at different concentration depicting the effect of synergy.

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