International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org Volume 2 Issue 6 ǁ June. 2013 ǁ PP.56-60

Comparative Study on the Effect of Three Flame Retardant Compounds on Flame Behaviour of a Roofing Thatch.

Odinma, S.C., Okoye, N.H. And Okoro, V.E.
(Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, P.M.B. 5025 Awka Anambra State Nigeria)

ABSTRACT: *The effectiveness of Potassium Aluminum Sulphate (Alum), Di-ammonium Hydrogen Phosphate and Ammonium Chloride as flame-retardant was studied by incorporating various concentrations of the flame-retardants into a grass commonly used as roofing thatch. Flammability test were carried out and the results show that the flame propagation rate, flame duration time and after-glow time decreased while ignition time and percentage add-on increased. These results are interpreted on the fact that on heating, these flame-retardants evolve substances that compete with the chemistry of pyrolysis / combustion of this grass.*
KEYWORDS: *Combustion, flame retardant, flame propagation, pyrolysis and roofing thatch.*

I. INTRODUCTION

The basis of natural building is the need to lessen the environmental impact of buildings and other supporting systems, without sacrificing comfort, health or aesthetics. Thatch is an affordable and a natural building material [1-2] use to cover a structure. It has been estimated [3] that thatch provides shelter for over 70% of Africans. The tradition of thatching has been passed down from generation to generation for thousands of years. This is because thatch posses an indispensible and unbeatable qualities which include excellent acoustic, electrical and thermal isolation properties to compare with any other roofing sheeting. However, thatched houses are more vulnerable to fire risk than those covered with other materials and it is therefore imperative that precaution be taken to reduce the risk. This precaution is the reason for this research! *"Fire, a good servant but a destructive master''*. The method by which the flammability of polymer can be reduced by chemical means is of long – standing importance and has engaged the mind of scientists [4-9] since the times of Alchemy and the Roman era [10]. Since then so much has been known that the burning behavior of certain textile materials, papers, and even timbers have been extensively investigated and documented [11-12]. In this work we reported on the comparative effect of Potassium Aluminum Sulphate, (K_2SO_4. $Al_2(SO_4)_3.24H_2O$), Ammonium Chloride (NH_4Cl) and Di-ammonium Hydrogen Phosphate $(NH_4)_2HPO_4$) on the fire characteristics of a roofing thatch known as *Antropogon tectorum.*

EXPERIMENTAL

Materials

The grass studied is *Antropogon tectorum* obtained from south-eastern part of Nigeria. It is referred to by its local Igbo name as *owa*. Potassium Aluminum Sulphate, (K_2SO_4. $Al_2(SO_4)_3.24H_2O$) was procured from the Federal Superphosphate Fertilizer plant at Kaduna Nigeria, and assay as: Al_2O_3(25.5%), Fe(0.0025%), insoluble mater(0.084%), and moisture content(18.47%); Ammonium Chloride(NH_4Cl) procured from BDH Laboratory supplies Pool, BH151 TD, England, and assay as: ex. Cl (98%), SO_4(0.01%) and Fe(0.05%); Di-ammonium Hydrogen Phosphate$(NH_4)_2HPO_4$) procured from M&B Laboratory Chemicals Dagenham, England and assay as: Cl.(<0.02%), SO_4(<0.02%),Fe(<0.002%), As(<0.0002%), Pb(<0.001%). All chemicals were used as supplied by the manufacturers.

Method

Flame-retardant treatment: the grass sample was dried in the electric oven at 105-110^oC to constant weight. Equal weights of the dry samples were completely immersed in equal volumes but different concentrations of flame-retardants contained in 1000cm^3 measuring cylinder, resident time, 48 hs. On removal from the dope, materials were again dried to constant weight in the electric oven (105-110^oC). Thus the weight of flame-retardant absorbed by samples was determined, using the expression [9]:
Add-on(%) = [(Y-X)/X] * 100/1
Where Y = weight of the sample after treatment
X = weight of the sample before treatment.
Determination of Ignition Time (I.T): the sample was clamped at 45^o at constant distance between its lower tip and small cigarette lighter (i.e. 4cm apart). Ignition time was recorded as the time interval between striking the

lighter and a tiny visually perceptible flame on the sample. It was necessary to take as many as fifteen readings per sample and the average calculated.

Determination of flame propagation rate (F.P.R): the sample was clamped at 45^o and was ignited at the base in a drought-free room. The distance traveled at a stipulated time interval by the char front was measured. The rate of propagation was calculated as the distance transversed per second.

Flame propagation rate(cm/s) = [distance moved by charfront(cm)]/[time(s)].

Determination of After Glow time (A.G.T): this was taken as the time between flame-out and the last visually perceptible glow [9]. Again, for each sample up to five readings were necessary and the average found/calculated.

Determination of flame duration time (F.D.T): this simple test is a measure of sustainability of combustion, which is a manifestation of pyrolytic and oxidative reaction going on at combustion. Sample was clamped at 45^o in a room with no air current, ignited at the base. The flame duration time is the time lapse between the onset of combustion or ignition and self extinguishment.

II. RESULTS AND DISCUSSION

Table 1: Fire characteristics of treated roofing thatch.

Con. (Mol/dm^3)	Ammonium Chloride (NH_4Cl)					Potassium Aluminum Sulphate(Alum) [$K_2SO_4.AL_2(SO_4)_3.24H_20$]					Di-Ammonium Hydrogen Phosphate [$(NH_4)_2HPO_4$]				
	Add-on(%)	IT(s)	FPR (cm/s)* 10^-1	AGT(s)	FDT(s)	Add-on(%)	IT(s)	FPR (cm/s)* 10^-1	AGT (s)	FDT(s)	Add-on(%)	IT(s)	FPR (cm/s)* 10^-1	AGT (s)	FDT(s)
0.00	0.17	1.20	2.00	184.32	268.83	0.20	1.07	2.03	185.41	270.61	0.17	1.10	2.00	186.03	269.53
0.01	0.24	1.47	1.98	113.74	177.87	3.51	1.65	1.97	183.46	235.65	0.20	1.43	1.95	140.07	180.73
0.05	0.24	1.91	1.82	48.31	190.00	5.42	2.68	1.34	92.64	202.57	0.21	2.71	1.72	98.03	167.22
0.10	0.30	1.97	1.42	3.04	231.37	6.35	2.91	1.28	31.18	111.87	1.08	2.97	1.59	57.78	154.25
0.15	0.38	2.08	1.25	0.90	193.26	6.64	2.98	1.20	10.98	83.42	1.71	3.49	1.35	55.00	96.56
0.20	1.52	2.86	1.25	0.89	182.44	10.90	3.53	1.17	44.38	24.85	5.02	3.92	1.20	22.10	72.09
0.50	4.78	3.22	0.58	0.05	65.47	15.32	4.78	1.12	17.18	21.63	6.81	5.23	1.07	0.00	13.80
1.00	9.56	5.06	0.35	0.02	15.86	21.75	5.79	0.70	30.81	32.96	10.15	8.04	1.00	0.00	5.48

The result of the percentage add-on of the flame-retardants is shown in Fig.1. It is clear that the quantities of flame-retardants absorbed by this thatch material depend on the liquor concentration. In the type of system, i.e. polymerics, 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: $(dJ)/(dt) = D[(d^2C)/(dx^2)]$; 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[13-14]. 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 (Table 1) in the flame propagation rate (Fig.3), After Glow Time (fig.4) and Flame duration time (fig.5), with the flame-retardant treatment is as follows:

Potassium Aluminum Sulphate : At high temperatures, it decomposes according to the equation:

$K_2SO_4.\ Al_2(SO_2)_2.\ 24H_2O = K_2SO_4 + Al_2O_3 + 3SO_3 + 24H_2O$……………….. (1)

Ammonium Chloride: appears to sublime upon heating. However, this process is actually decomposition into ammonia and hydrogen chloride gas

$NH_4Cl = NH_3 + HCl$ ……………………………………………..(2)

$HCl = H^{\cdot} + Cl^{\cdot}$ …………………………………………………….(3)

Di-ammonium Hydrogen Phosphate (DAP): The flame-retardant mechanism of DAP is achieved according to the following mechanism:

$(NH_4)_2HPO_4 = NH_{3(g)} + NH_4H_2PO_{4(s)}$ ………………………………..(4)

$NH_4H_2PO_{4(s)} = NH_{3(g)} + H_3PO_{4(l)}$ ....(5)

$2H_3PO_4 = P_2O_5 + 3H_2O$. ……………………………………………….(6)

The flame inhibiting property of Di-ammonium Hydrogen Phosphate, Potassium Aluminum Sulphate, and Ammonium Chloride are interpreted in terms of the vapour, liquid and condensed phase mechanisms as the case may be. The gaseous products, SO_3, H_2O, NH_3 and HCl dilute the combustible volatile pyrolysates of cellulose, thereby reducing their concentration in the flame zone. The evolution of water absorbs heat and thereby reduces the transport processes of heart conduction and fluid flow. The free radicals H· and Cl· have the ability to scavenge the OH· and O· radicals that are essential for the sustenance of combustion. K_2SO_4 and alumina (Al_2O_3) are excellent heat conductors that deflect heat away from the burning surface. H_3PO_4 is a very viscous liquid which act as a film on the cellulose filbers, thereby damming up the issuing pyrolysate. Phosphorus-Oxy acids also catalyze cellulose pyrolysis via char formation. P_2O_5 has the ability of directing cellulose combustion to the production of carbon monoxide instead of carbon dioxide (7).

$5C + P_2O_5 = 5CO + 2P$. ………………………………………… (7)

In regard to equation (7), the exothermic reactivity of the system reduces and hence serves as fire extinguisher.

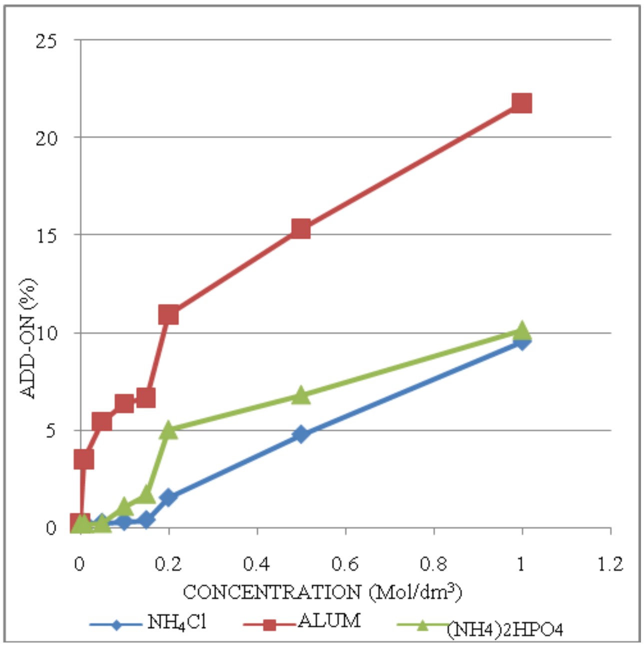

Figure 1: The effect of concentration of Flame Retardant on Add-On.

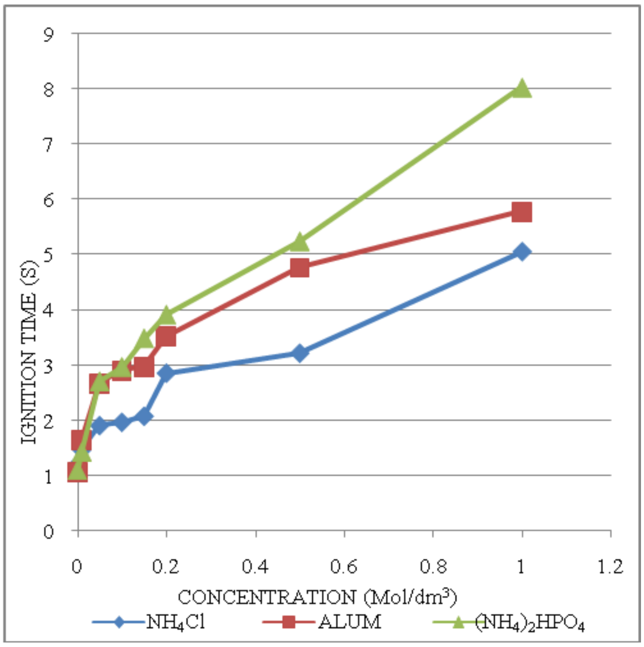

Figure 2: The effect of concentration of Flame Retardant on I.T.

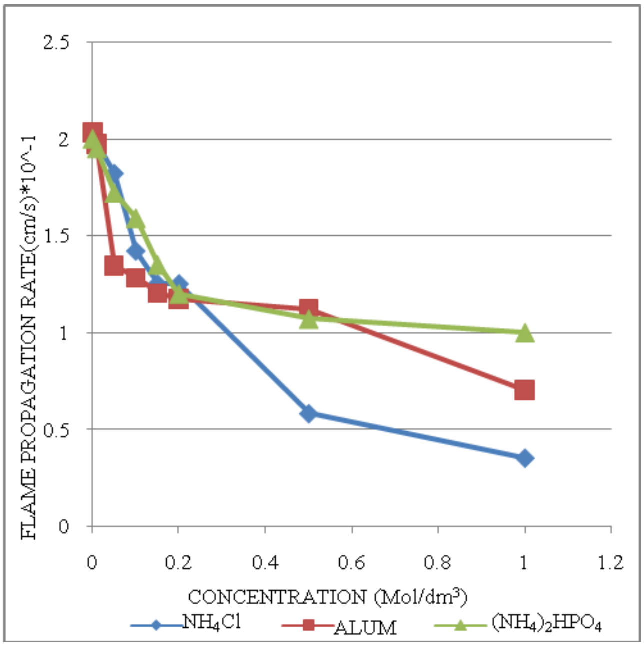

Figure 3: The effect of concentration of Flame Retardant on F.P.R.

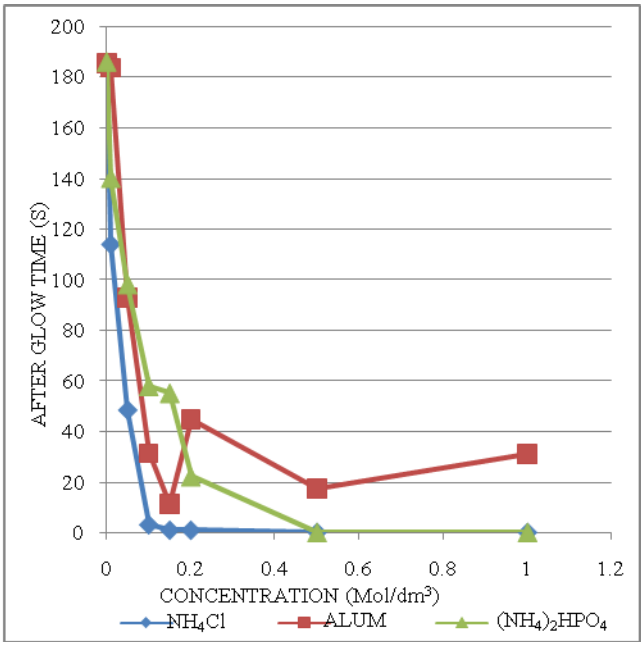

Figure 4: The effect of concentration of Flame Retardant on A.G.T

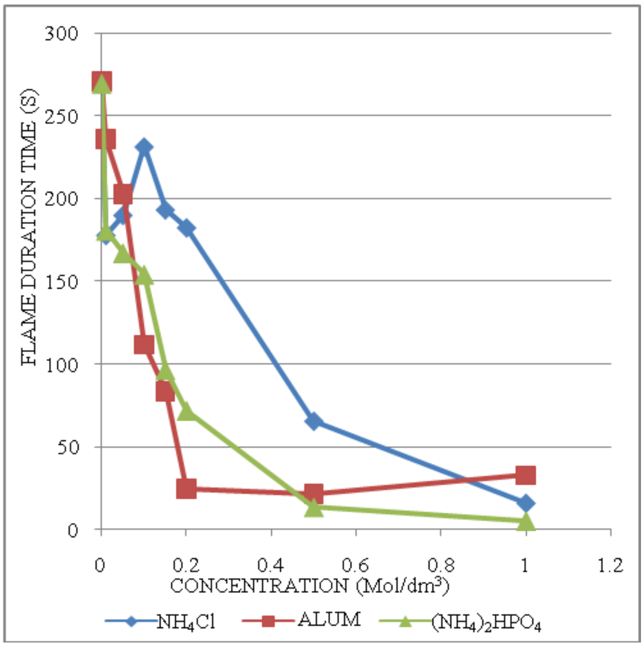

Figure 5: The effect of concentration of Flame Retardant on F. D.T

III. CONCLUSION

It is concluded from this investigation that Potassium Aluminum Sulphate, Di-ammonium Hydrogen Phosphate and Ammonium Chloride function as flame-retardants for the roofing thatch by complex processes that entail the vapours, liquid and condensed phase mechanisms. Hence, it is clear (Table 1) that these three flame retardants are suitable for treatment of thatch to impart reluctance to burning and to answer the 'call-for-help' on flammability nature of roofing thatch, to save lives and properties. Thatch roof is constructed in layers, should the flame retardant leach from the top-most layer after a long exposure to rainfall, the underlying layer remains dry and intact. Since over 80% of fires that start from the roof do so from below and not from top, the aim of our application remains untouched.

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