American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Reducing the Flammability of Gmelina arborea Wood Using Flame Retardants

Rosemary Arinze[a]*, Pauline Chris-Okafor[b], Nkechi Okoye[c], Chinasa Iziga[d]

[a,b,c,d]*Department of Pure and Industrial Chemistry, Faculty of Physical Sciences, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Anambra State, Nigeria*

[a]*Email: ru.arinze@unizik.edu.ng*

[b]*Email: pu.chrisokafor@unizik.edu.ng*

[c]*Email: nh.okoyeunizik.edu.ng*

[d]*Email: cg.iziga@unizik.edu.ng*

Abstract

The purpose of this study is to reduce the flammability of Gmelina arborea using fire retardants. This becomes necessary because fire has caused a lot of devastating effect to mankind since its discovery. Gmelina arborea splints were immersed in different concentrations of antimony trichloride, ammonium sulphamate and mixture of the antimony trichloride and ammonium sulphamate to determine the ignition time (IT), flame propagation rate (FPR) and after-glow time (AGT). The results indicated reduction in flame propagation rate and after-glow time for the three flame retardants while ignition time was increased with increase in concentration for the retardants. It was also observed that the combined flame retardants gave the highest ignition time and least flame propagation rate and after-glow time among the three flame retardants used. These flame retardants can be used especially the mixture of antimony trichloride and ammonium sulphamate to hinder/slow the ignitability of Gmelina arborea.

Keywords: AGT; Ammonium sulphamate; Antimony trichloride; FPR; flame retardant; Gmelina arboea; ignition time.

1. Introduction

Man has utilized wood since antiquity. It is one of the most versatile renewable important and endlessly source of energy and has played key role throughout human history [1-3]. It provides excellent performance in many applications such as, building, construction, food, medicine, fuel, and making other products [1, 4 & 5].

----

* Corresponding author.

These woods in the form of cellulose ignite very easily and pose considerable fire risk. Fire is the rapid oxidation of a material in the exothermic chemical process of combustion, releasing heat, light and various reaction products [6 & 7]. Fire is destructive in nature and occurs when a flammable material accompanied with sufficient amount of an oxidizer (e.g. oxygen) is exposed to a source of heat, and is able to sustain a rate of rapid oxidation that produces a chain reaction [8]. The discovery of fire and its utilization prompted the emergency of flame retardants as a resort to control flammability of combustible materials, as many damages due to fire has been recorded [1, 9-11]. Flame retardant is a chemical compound when incorporated into combustible materials serves to slow or hinder the ease of ignition and propagation [1]. They are designed to delay the risk of fire starting in case of contact with a small heat source. Modern-day flame retardants are efficient for use in reducing fire hazards; they interfere with the flames, inhibiting the free radicals that propagate flame reactions. The decomposition of flame retardant produce a new catalytically active surface which is effective at preventing the free radicals required for flame propagation. Thus, provide cooling and blanketing property to the material [12]. Flame retardant can also increase the amount of water and char formed thereby hindering the material from igniting. Three methods exist for the addition of flame retardant to wood. They include: laminating and coating treatments, impregnation treatment and chemical modification. Of the three methods, laminating and coating treatment is widely used to enhance the flame retardancy of wood. However, this approach has a shortcoming, in that if the coating layer is damaged or the charring layer falls off during the fire, the fire-retardant performance is lost [13 & 14]. Based on this findings, we report on reducing the flammability of various Gmelina wood splints with different concentrations of antimony trichloride, ammonium sulphamate and mixture of antimony trichloride and ammonium sulphamate; employing the impregnation treatment method.

2. Materials and Methods

2.1. Materials

The gmelina wood was obtained from the timber market, Awka in Nigeria. The antimony trichloride and ammonium sulfamate were produced by Loba Chemie PVT, Ltd., Mumbai, India.

2.2. Procedure

The Gmelina wood sample was cut into splints of uniform sizes of length 45cm, width 0.6cm and thickness of 0.4cm. The wood splints were sun dried for one week and oven dried at 105^{o}C until constant weight was obtained. Different concentrations of $SbCl_3$ and N_2H_6SO each were prepared by dissolving in 800cm^3 of distilled water and also by mixing concentration of each flame retardant together. Each solution was thoroughly homogenized to obtain uniform mixture. Three splints were soaked in each concentration and left for one week. They were allowed to dry at room temperature for three days and oven dried at 105^{o}C to constant weight. The percentage concentration of the amount of $SbCl_3$ and $H_6N_2O_3S$ absorbed were calculated. The untreated splint was used as control.

$$\%\, concentration\ of\ the\ FR\ absorbed = \frac{X - Y}{Y} \times 100 \qquad (1)$$

Where, X= Weight of treated wood and

Y = Weight of untreated wood

FR = stands for Flame Retardant

2.3. Characterization of the treated and untreated wood splints

The ignition time, flame propagation rate and afterglow time were performed to discover the effectiveness of $SbCl_3$, $N_2H_6SO_3$ and mixed ($SbCl_3$ and $N_2H_6SO_3$) during combustion of the wood splints of various concentrations of the flame retardants.

2.3.1. Determination of the Ignition time

Each splint was clamped vertically in a draught free room. It was ignited at the base using a cigarette lighter. The ignition time was taken as the time between which the ignition source came in contact with the base of the sample and the time a tiny spark was observed on the splint. It was performed thrice for each sample and the average taken.

2.3.2. Determination of the Flame propagation rate

As earlier mentioned, the vertically clamped treated sample was ignited at the base with a lighter. The distance travelled by the char front and the time taken were recorded. The same method was repeated for other splints and each concentration repeated thrice and the average calculated.

$$FPR\ (cm/sec) = \frac{Distance\ travelled\ by\ the\ char\ front\ (cm)}{Time\ taken\ (\text{sec})}$$

Where FPR= Flame Propagation Rate

2.3.3. Determination of After-glow time

The afterglow times were obtained by noting the time in seconds between flame extinction and the last visually perceptible glow. Again for each wood sample of different concentrations, the average of the three splints readings was used. In other words after-glow time is the time it takes the glow to disappear after the flame was put off.

3. Results and Discussion

3.1. Percentage efficiency of the flame retardants on wood splints

Percentage efficiency indicates the amount of flame retardant each wood splint was able to absorb. Table 1 and Figure 1 shows the quantity of flame retardant absorbed by each wood splint. The efficiency of the three flame retardants increased with increase in concentration.The antimony trichloride gave best efficiency among the three retardants. This is followed by mixture of the antimony trichloride and ammonium sulphamate, and then ammonium sulphamate while ammonium sulphamate gave the least efficiency.

Table 1: Percentage efficiency of the amount of $SbCl_3$and $H_6N_2O_3S$ absorbed

Concentration (g/cm^3)	Percentage efficiency of $SbCl_3$ absorbed (%)	Percentage efficiency of $H_6N_2O_3S$ (%)	Percentage efficiency of $SbCl_3$&$H_6N_2O_3S$ (%)
0.0	0.0	0.0	0.0
4	12.35	18.52	16.67
8	25.53	19.75	24.65
12	27.16	22.22	30.25
16	32.06	26.54	33.33
20	43.62	37.03	37.04
24	50.62	41.36	41.36

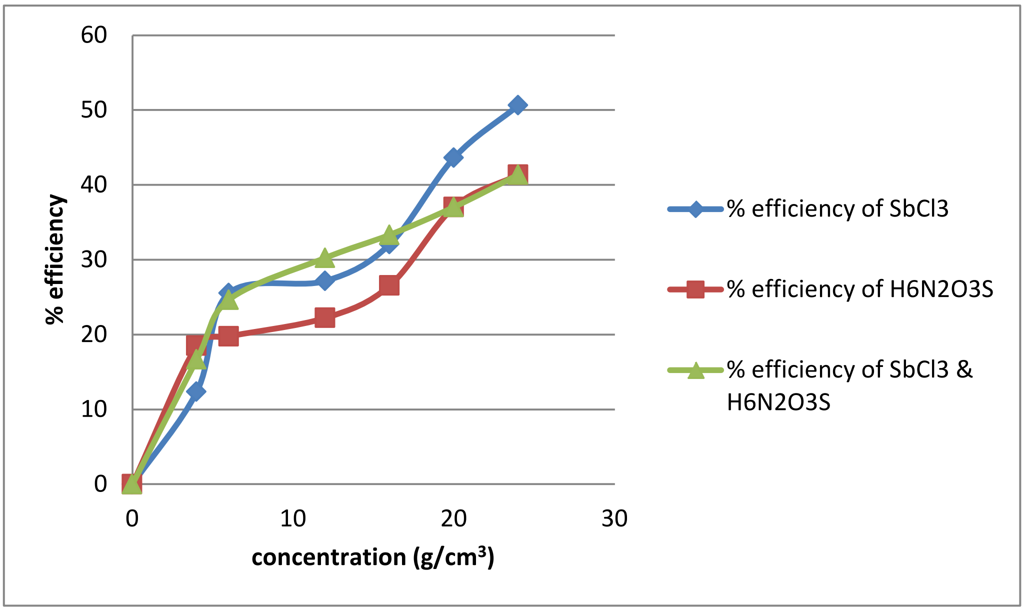

Figure 1: Percentage efficiency of the flame retardants on wood splints

3.2. Effect of flame retardants on ignition time of wood splints

It is evident in Table 2 and Figure 2 that the ignition time is raised with increase in concentration. As the wood splint receives heat from the flame, the temperature increases and the heat redistributes to the other parts of the wood splint by conduction to such an extent that it induces decomposition of the wood splint resulting to ignition. The presence of ammonium sulphamate and antimony chloride raises the ignition temperature of the wood splints. The untreated wood splint gave the lowest ignition.

Table 2: Effect of antimony trichloride, ammonium sulphamate and mixture of antimony trichloride and ammonium sulphamate on ignition time

Concentration (g/cm^3)	Average ignition time of $SbCl_3$ (s)	Average ignition time of $H_6N_2O_3S$ (s)	Average ignition time of $SbCl_3$&$H_6N_2O_3S$ (s)
0.0	10.	10	10
4	14	21	22.5
8	18	24	26
12	21	26.5	31
16	32.5	31	35
20	34.5	32.5	37
24	42	33.5	41.5

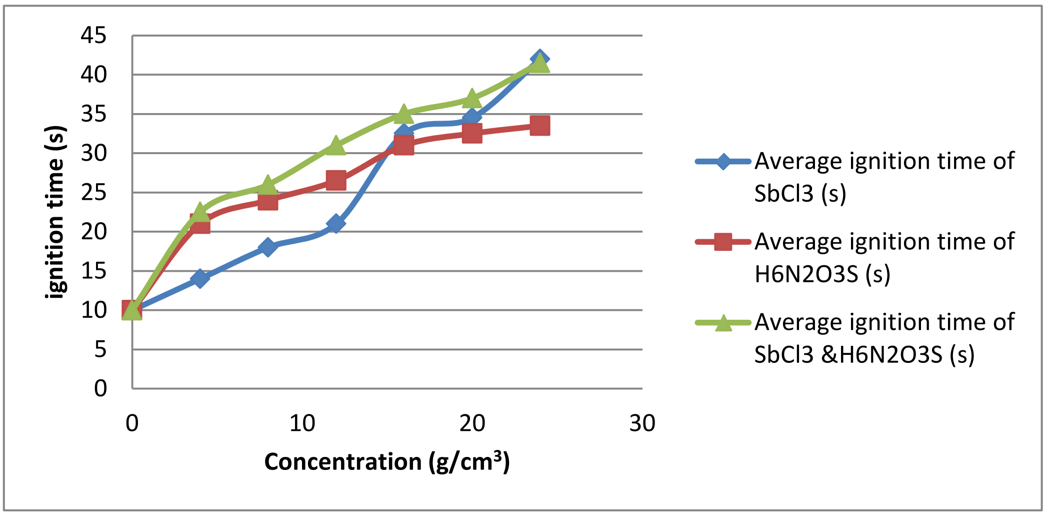

Figure 2: Effect of flame retardants on ignition time of wood splints.

From consideration of the three retardants used, it is observed that even at lower concentration, there is enhancement in the ignition time. Wood splints treated with the flame retardant mixture of ammonium sulphamate and antimony chloride gave the highest ignition time. This is because ammonium sulphamate and antimony trichloride had a falme retarding effect on the wood. The effect of ammonium sulphamate was steady with respect to the increase in concentration. On the other hand, the effect of antimony chloride was gradual at lower concentration but increases rapidly at higher concentration. Thus, it can be deduced from this work that ignition time increased much as concentration of the antimony trichloride and ammonium sulphamate increased.

3.3. Effect of flame retardants on flame propagation rate of wood splints

In Table 3 and Figure 3, it is seen that the flame propagation rate decreased as concentration of antimony trichloride, ammonium sulphamate and their mixture increases. This shows that the retardants used act as good flame retardants on Gmelina arborea. This is similar to the work by Erike and his colleagues (1995) [15]. The combined retardant of $SbCl_3$ and $H_6N_2O_3S$ gave the least flame propagation rate.

A better retarding effect was observed with the combined retardant of $SbCl_3$ and $H_6N_2O_3S$ compared to that of antimony trichloride and ammonium sulphamate. This is because ammonium sulphamate on heating decomposes to give ammonia, nitrogen (iv) oxide and sulphur (iv) oxide as byproducts which do not support combustion. These products form a coating around the material and exclude oxygen, thereby inhibiting the free radicals that sustain the fire. On the other hand, antimony trichloride acts as free radical trap, and takes up free radicals. It also acts as a dehydrating agent that increases char formation [12].

Table 3: Effect of antimony trichloride, ammonium sulphamate and mixture of antimony trichloride and ammonium sulphamate onflame propagation time

Concentration (g/cm^3)	Average FPR of $SbCl_3$ (cm/s)	Average FPR of $H_6N_2O_3S$ (cm/s)	Average FPR of $SbCl_3$&$H_6N_2O_3S$ (cm/s)
0.0	0.17	0.17	0.17
4	0.13	0.13	0.10
8	0.13	0.10	0.09
12	0.10	0.07	0.08
16	0.08	0.06	0.05
20	0.06	0.05	0.05
24	0.06	0.05	0.04

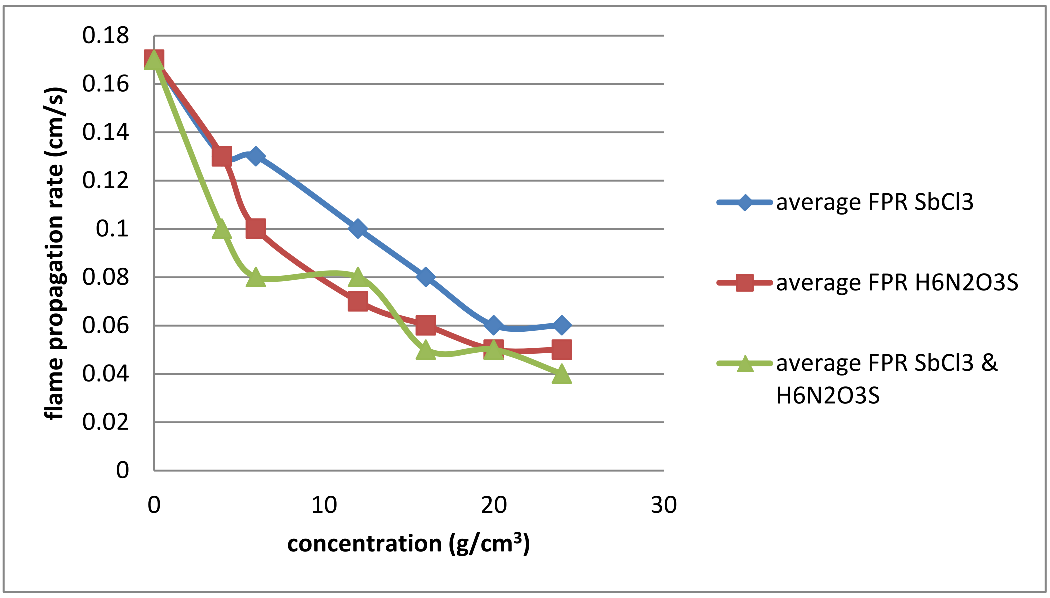

Figure 3: Effect of flame retardants on flame propagation rate of wood splints.

3.4. Effect of flame retardants on after-glow time of Gmelina wood splints

Figure 4 shows that increase in the concentration of antimony trichloride and ammonium sulphamate and their mixture, reduced the afterglow time .The mixture of retardants is the first to extinguish, followed by ammonium sulphamate and then antimony trichloride. Glow is a surface oxidation process that depends on the quality of carbonaceous char left at the end of heating as well as available oxygen. Since the ability of the wood to form char after combustion decreased as the concentration of the antimony trichloride and ammonium sulphamate in the wood sample increased. This is similar to the result obtained by Onuegbu and his colleagues 2011[16].

Table 4: Effect of antimony trichloride, ammonium sulphamate and mixture of antimony trichloride and ammonium sulphamate on after-glow time

Concentration (g/cm^3)	Average AGT of $SbCl_3$ (s)	Average AGT of $H_6N_2O_3S$ (s)	Average AGT of $SbCl_3$&$H_6N_2O_3S$ (s)
0.0	203	203	203
4	185	118	55
8	174.5	105	52.5
12	124	99.5	49.5
16	113	90	36
20	102.5	77	26
24	86	55	19

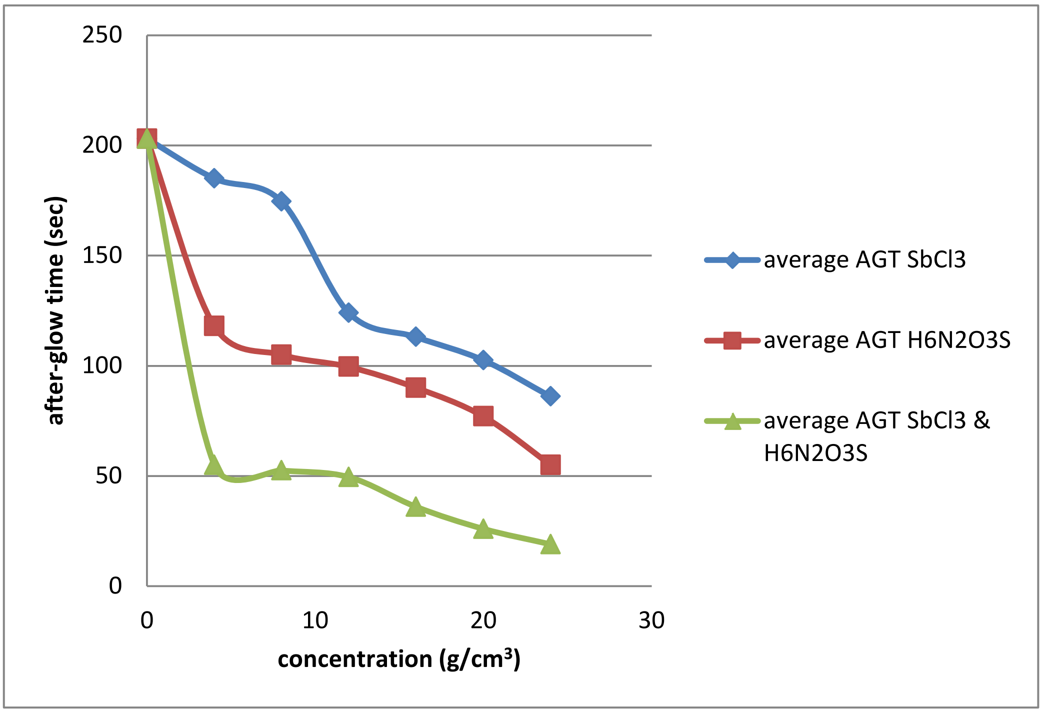

Figure 4: Effect of flame retardants on after-glow time of Gmelina wood splints

4. Conclusion

Antimony trichloride, ammonium sulphamate and mixture of antimony trichloride and ammonium sulphamate are good fire retardants in delaying and resisting ignition. The mixture of the two retardants gave the resistant to ignition, lowest flame propagation rate and after-glow time. There also was remarkable improvement when the wood splints were treated individually with each of the flame retardants but it was more pronounced when the two flame retardants were combined at different concentration depicting the effect of synergy. Timbers treated with these flame retardants especially with the mixture of the retardants will resist onset of fire. Hence, impregnation treatment method can effectively impart flame resistance to wood.

5. Recommendations

We employed the impregnation method to enhance the fire retardancy of different splints of Gmelina arborea wood. It was showed that significant increase in fire resistance of wood can be achieved using this method. Thus, impregnation method should be pursued by the timber industry, as it would be simpler and cheaper than chemical modification and laminating and coating methods. Impregnation method can be used for thin veneers, wood particles, wood fibers, and other wood raw materials. For large-sized wood pieces, impregnation method by soaking might be difficult. Therefore, in the future work, we need to explore other ways to achieve impregnation treatment aside soaking, to make the treatment of large-sized wood pieces easier.

References

[1]. A.R. Horrocks, D. Price and M. Ane. “Flame Retardant for Cellulosic Materials.”Journal of Fire Sciences, p.235, 1987.

[2]. G. Bashiru and A. N. Eboatu. “Effect of Flame Retardant Treatment on the Thermal Behaviour of Some Tropical Timbers.”Journal of Applied Polymer Science, vol 39, pp. 109-118, 1990.

[3]. R.M. Rowel. Handbook of Wood Chemistry and Wood Composites.Florida: CRC Press, 2005, pp. 80-140.

[4]. A.N. Eboatu. (1992).Fire, Flammability and Fire Fighting.Lagos: Anchor Educational Press, 1992, pp. 6-33.

[5]. E.W. Ducane. Wood Research Station Review, New York:Macmillian Company, 1978, p. 124.

[6]. R. Fried. Polymer Science and Technology. 2nd ed.,New Jersey: Person Education Inc, 2003, pp. 43.

[7]. P. Dufton. Flame Retardants for Plastics,United Kingdom: Repratechnology Ltd, 2003, pp. 17-18.

[8]. P. Parma and G.B.Rathod. “Basic Facts of Fire – A Forensic Review.” International Journal of Current Research and Review, vol. 04, issue 19, pp. 181-191, 2012.

[9]. H. McGraw. Encyclopedia of Science and Technology.8th edition, England: R. R,Donnelly & Sons Comp, 1997, pp. 127-154.

[10]. S. Silvana. “Synthesis, Characterization and Application of Polymeric Flame Retardant Additives Obtained by Chemical Modification.” Ph.D Thesis, Universitat Elvira I Virgili, Tarragon, 2012.

[11]. R. U. Arinze, A. N. Eboatu, P. I. Udeozo, J. I. Dioha and U. I. Okoye.“Flame Retardant Paint Treatment of Some Tropical Timbers.”European Journal of Applied Science, vol. 7, issue 4, pp. 195-198, 2015.

[12]. A.N. Eboatu, B. Garba and I.O. Akpabio. “Flame Retardant Treatment of some Tropical Timbers.”Fire and Materials, vol. 17, pp. 39-42, 1993.

[13]. T. Mariappan (September 6th 2017). “Fire Retardant Coatings.” New Technologies in Protective

Coatings, [Carlos Giudice and Guadalupe Canosa, IntechOpen], pp. 101-122. DOI: 10.5772/67675. Available from: https://www.intechopen.com/books/new-technologies-in-protective-coatings/fire-retardant-coatings

[14]. F. Wang, Q. Wang and X. Wang. "Progress in Research on Fire Retardant–Treated Wood and Wood-Based Composites: A Chinese Perspective." Forest Products Journal, vol. 60, No. 7/8, pp. 668-678, 2010.

[15]. E. Erike, Igbelina and A.N. Eboatu. "The Combination Effect of Known Flame Retardant Behaviour of Timber Samples."Journal of Science, Engineering and Technology, vol. 2, pp.267-273, 1995.

[16]. T.U. Onuegbu, E.T. Umoh andJ.E. Iwuchukwu. "Flame retardant effects on Flexible polyurethane foam treated with potassium Aluminum Sulphate."ARPN Journal of Science and Technology, vol. 2, issue 11, p. 1098, 2011.