INVESTIGATING THE FLAMMABILITY STATUS OF SOME POTENTIAL FIRE TOLERANT TREES IN SOUTH-EAST NIGERIA

Okafor, V.N.[1], Obiefuna, J.N.[1], Obiadi, M.C.[1], Osuorah, A.[2], Anyalebechi, R.I.[3], Okafor, U.W[4].

[1]Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Nigeria
[2]Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria
[3]Department of Science Laboratory Technology, Federal Polytechnic Oko, Anambra State, Nigeria
[4]National Board for Technology Incubation, Federal Ministry of Science and Technology, Abuja, Nigeria
Email: vnw.okafor@unizik.edu.ng

ABSTRACT

The aim of this study was to investigate the fire tolerant potentiality and flammability status of ten tropical trees in South-East Nigeria. The tree species: *Daniellia oliveri*, *Vitex doniana, Tectona grandis, Delonix regia, Newboulia laevis. Azadirachta indica, Dialium guineense, Terminalia superba, Manilkara obovata* and *Invingia gabonensis* were identified and named by taxonomists. An item structured instrument which was developed by the researchers to reflect the six points modified Likert scale of strongly agree, agree, somewhat agree, somewhat disagree, disagree, strongly disagree, was used to elicit information from the respondents who were mainly seasoned wood dealers of above 60 years of age. Major tool of analysis was Analysis of Variance (ANOVA). *Gmelina arborea*, treated with 2M borax for 48 hours was the control and referred to as fire retardant treated wood (FRTW). Physical properties of wood (moisture content and density) as well as flame characteristics (ignition time, flame propagation rate, after glow time, flame duration and ash formation) of the control and the ten tropical tree species were carried out using published protocols. Test of significance (p-values) for all the tree species were greater than 0.05 at 95% confidence interval which indicates that there was no significant difference among all the tropical trees investigated. The values for physical properties and flame characteristics of the trees vary among the selected species but compared favourably with that of the FRTW. This study has shown that the timbers investigated could tolerate fire.

Keywords: Flammability status, Fire tolerant trees, Flame characteristics, FRTW, South-East Nigeria

1. INTRODUCTION

The use of dry natural woods in building, construction and for furniture amongst others is well established [1]. The application of wood in such diverse areas as in construction of boats, vehicles, buildings, household furniture of immense variety, bridges as well as for generation of chemicals and pharmaceuticals and as fuel for small scale furnace works have been reported [2]. Combustibility of wood, whereby in the presence of sufficient heat energy, pyrolysis or gasification takes place has constituted the major short fall in the utility of this important resource [3]. Pyrolysis/combustibility is the mode by which useful energy and chemicals are derived from wood. Wood is generally regarded as possessing a high degree of combustibility when sufficient quantity of heat energy is applied [1]. It can be ignited by a variety of fire sources and once ignited, the flame may spread rapidly across the surface with slower progress

through the bulk until the fire becomes general. This is the cause of significant numbers of injuries and fatalities in fires reported yearly by various countries and other workers [4-6].
The phenomenon of combustion in terms of pyrolysis and flammability has been the subject of extensive studies directed towards three primary interests: building and contents, forest and grassland fires [1].

In its broadest sense, the performance of wood in fires can be described in terms of three distinct burning phenomena namely ignition, flaming and glowing, which present different potential hazards, and should be approached in different ways. Literatures abound on

thermal decomposition of cellulose or lignocelluose [7-12). The ignition properties of cellulose materials have been reviewed and discussed in various publications [13-15. Eboatu and Alhaji [16] reported that most of the trees planted during the yearly tree planting ritual do not survive the next planting ceremony because the trees are not selected on the basis of their botanic or chemical nature. Okonkwo and Eboatu [17] in their work on fire resistance properties of tropical timbers agreed with the assertion of Eboatu and Alhaji that chemical nature of trees determines their fire tolerance.

Moreover, the flammability states of trees were not always considered by majority of timber users in various applications. Thus, the vast resources of the tropical rainforests have therefore become of decisive interest for future timber and forest planning, renewal and development. As a result, a lot of efforts have been made in the investigation of flame properties of some tropical timbers. Nonetheless, it is surprising that little or no literature is available on the flammability status of the timbers, hence this study.

2. MATERIALS AND METHODS

2.1 Materials

An item structured instrument which was developed by the researchers was used to elicit information from the respondents. A prototype of the questionnaire is shown in Figure 1 and Table 1. The ten (10) tropical timbers were procured from different rainforests in the South Eastern region of Nigeria (Table 2) based on the information obtained from respondents to questionnaires.
The apparatuses used in this work: stopwatch, clamp and retort stand, crucible with lid, top loading Mettler balance, muffle furnace, vacuum oven etc. were collected from the Research Laboratory of the Department of Pure and Industrial Chemistry of Nnamdi Azikiwe University, Awka. Analytical grade reagent, borax also called sodium tetraborate was procured from Sigma Aldritch (Germany).

2.2 Study Design and Statistical Method

The study adopted experimental and descriptive survey designs. Ikeagwu [18] noted that studies of this nature use the survey method to look for information on facts, practices and opinions of the respondents on the issues surrounding the subject matter of the investigation. To Obasi [19], the use of survey is always adopted because it provides an important means of gathering information especially when the necessary data cannot be found in statistical records in form of secondary data. In the test of significant difference, One Way Analysis of Variance

(ANOVA) is the most suitable tool as it has the capacity to show the existence of difference at 5% level of significance [20]. Two hypotheses, H_0 and H_1 were stated and tested for:

H_0; there is no significant difference among samples of interest.

H_1; there is significant difference among samples of interest.

The result of the p- value (significance value) was used to accept or reject either of the hypotheses.

2.3 Sample Preparation

Gmelina arborea was treated by method reported by Nwajiobi *et al*, 2016 [21] and used as control. The physical and flammability properties of the control and all the trees were investigated using published protocols [1, 22-24].

3. RESULTS AND DISCUSSION

3.1 Statistical Results

The Analysis of Variance results for the tree species are shown in Tables 3-12. In the Tables, the p-values in all the tree species were greater than 0.05 at 95% confidence interval. Hence, H_0 was accepted and H_1 was rejected for the tree species. These results show that the tree species are fire resistant since the results are in agreement with those of Vines [25] and Vander-Weidel and Hartnett [26].

Name ---

Sex: Male ☐ Female ☐

Age: ☐

Home Town: ____

L.G.A.: ____

State: ____

Rate the tree species on a 6-point scale

Strongly agree	-	(6)
Agree	-	(5)
Somewhat agree	-	(4)
Somewhat disagree	-	(3)
Disagree	-	(2)
Strongly disagree	-	(1)

Figure 1: Personal Information and Rating Method

Table 1: Prototype Questionnaire used for all the Tree Species

S/N	Items	1	2	3	4	5	6
1	This tree species is used traditionally in control of erosion menace and desert encroachment.						
2	This species can be used for afforestation						
3	This species grows actively even in the early dry season						
4	The moisture content of this species is very high						
5	The tap root of this species is well above 2 meters below the underground growing point						
6	The bark of the species is corky and thick						
7	The tree possesses only fibrous roots that spreads more than 2 meters in diameter, underground						
8	This tree species survives bush burning by re-sprouting						
9	After bush burning, this species produces watery like liquid (sap) on the bark of the trunk						
10	After wild fire, this species recovers vegetatively by developing underground wood suffrutices or swollen root system						
11	This species has gone into extinction as a result of incessant forest fires over the years						
12	Method of propagation of this tree species encourages its prevalence						
13	When this species is ignited by an external source when dried, it burns slowly						
14	There is high accumulation of char and/or ash when a dried wood of this tree is burnt						
15	This species can be used as firewood for fuel few days after forest fires.						
16	Generally, this species is highly flammable when dried and ignited						

Table 2: Tree Species and locations where they were procured

S/N	State	LGA	Community	Tree Species (Botanic name)
1	Abia	Umunneochi	Lekwesi	*Daniellia oliveri*
		Umuahia South	Amaigbo	*Vitex doniana*
2	Anambra	Ayamelum	Ifite Ogwari	*Tectona grandis*
		Awka South	Ifite Awka	*Delonix regia*
3	Ebonyi	Izzi	Iboko	*Azadirachta indica*
		Ishielu	Nkalagu	*Dialium guineense*
4	Enugu	Oji River	Oji	*Terminalia superba*
		Uzo Uwani	Umulokpa	*Manilkara obovate*
5	Imo	Ihite Uboma	Isinweke	*Invingia gabonensis*
		Oguta	Oguta	*Newboulia laevis*

Table 3: ANOVA for *D. oliveri*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	1.492	14	0.107	0.127	1.00
Within Groups	1874.900	2235	0.839		
Total	1876.392	2249			

Table 4: ANOVA for *V. doniana*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	5.956	14	0.425	0.993	0 .458
Within Groups	957867	2235	0.429		
Total	963.822	2249			

Table 5: ANOVA for *T. grandis*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	5.980	14	0.427	0.325	0.991
Within Groups	2937.607	2235	1.314		
Total	2943.586	2249			

Table 6: ANOVA for *D. regia*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	.326	14	0.023	0.093	1.00
Within Groups	558.493	2235	0.250		
Total	558.820	2249			

Table 7: ANOVA for *N. laevis*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	.437	14	0.031	0.071	1.00
Within Groups	937.947	2235	0.442		
Total	988.384	2249			

Table 8: ANOVA for *A. indica*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	6.862	14	0.490	1.193	0.273
Within Groups	918.127	2235	0.411		
Total	924.989	2249			

Table 9: ANOVA for *D. guineese*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	1.909	14	0.136	0.250	0.998
Within Groups	1217.867	2235	0.545		
Total	1219.776	2249			

Table 10: ANOVA for *T. superba*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	22.153	14	1.582	0.823	0.644
Within Groups	4296.447	2235	1.922		
Total	4318.500	2249			

Table 11: ANOVA for *M. obovata*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	6.864	14	0.490	0.593	0.873
Within Groups	1848.560	2235	0.827		
Total	1855.424	2249			

Table 12: ANOVA for *I. gabonesis*

	Sum of squares	Df	Mean square	F	Sig.
Between Groups	1.376	14	0.098	0.240	0.998
Within Groups	916.660	2235	0.410		
Total	918.036	2249			

Df = Degree of freedom, F value = Variance of the group means. Sig. = Significance value

3.2 Physical and flame Characteristics

In Table 13, it is shown that the timbers may be ranked differently depending upon which parameter is considered and no simple correlation of these parameters exists. The tree species differ remarkably in performance as far as their flammability properties are concerned. Using a simple test method, other workers [27, 28] noted similar variations among wood specimens and they were classified accordingly. Other flammability test methods have been used but it is difficult to compare results [29]. This is because for any given test method, there is considerable variability because of the differences in apparatus, specimen size and position, time of exposure to flame or radiation and the general sample flammability characteristics tested [1].

Under constant ignition and environmental conditions, the principal factors affecting the flammability processes include the variations in the composition of the substrate ranging from different types of wood to different types of natural plant, fibres/cells, and the effect of these on the phenomena of heat and mass transfer [1, 30]. In addition to these factors, trace amounts of inorganic impurities or contaminants could account for one of the observed differences [10].

The moisture contents of all the tree species as shown in Table 13 ranged from 8.02 to 10.73%. The moisture content is the difference between the weight of sample before and after drying. As expected, the moisture content of all the tree species were within the same range. This indicates that all the timbers contain appreciable amount of moisture, a factor that contributes to flammability resistance [26]. The density of the timbers ranged between 0.45 and 1.16gcm^{-3} with *I. gabonesis* having the highest density and *D. olieri,* the least dense wood. It is expected that density should have proportional relationship with ignition time but closer examination of

Table 13 suggests that there is no correlation between timber density and ignition time. This observation is not in agreement with the findings of Okoye *et al.*, 2014 [31]. In our previous work [32], it was established that there are highly significant correlations between wood density and both ignition time and flame propagation rate as well as wood density and limiting oxygen index. The disagreement of the present work with those of Okoye *et al*. and our previous work could be explained by the fact that other factors such as the cellular nature of the wood, thermal conductivity, presence of inorganic salts in their cells etc., are not likely to be exactly the same for all the timbers [33]. Furthermore, Momoh *et al.*,1996 [1] reported that measurement technique for density cannot be said to be perfect and that any procedure for wood density based on direct measurement of weight and volume can be considered accurate only if the wood sample has been first extracted with suitable organic solvent to remove extraneous resins, oils, gums, fats, etc. [34, 35]. These materials thicken cell walls, block potential sites for water adsorption and absorption, alter potential wood swelling and shrinkage properties and thereby interfering with the accurate characterization of wood tissue [1].

Table 13: Physical and Flame Characteristics of the Timbers

	Moisture content (%)	**Density (gcm^{-3})**	**Ignition time (s)**	**Flame propagation rate (cm/s)**	**Flame duration (s)**	**Afterglow time (s)**	**Ash formation (%)**
*FRTW	10.61	0.52	8.00	0.16	22.00	129.00	0.26
D. oliveri	9.91	0.45	3.00	0.25	7.00	150.00	1.26
V. doniana	10.73	0.51	5.00	0.19	27.00	186.00	2.38
T. grandis	8.02	0.54	6.00	0.17	25.00	25.00	1.12
D. regia	10.02	0.70	5.00	0.14	45.00	95.00	0.36
N. laevis	10.70	0.71	4.00	0.14	15.00	169.00	1.53
A. indica	11.56	0.72	7.00	0.13	15.00	124.00	0.29
D. guinease	9.91	0.81	8.00	0.13	24.00	117.00	0.19
T. superba	10.13	0.87	3.00	0.16	17.00	60.00	0.56
M. obovate	10.61	1.13	10.00	0.09	11.00	103.00	0.19
I. gabonesis	10.44	1.16	9.00	0.12	14.00	64.00	0.96

*Fire retardant treated wood.

The results in Table 13 also indicate that *M. obovata* was reluctant to ignite while *D. oliveri* showed propensity to ignition. Ignition is the releasing of energy to trigger the initial chemical action of combustion. Ignition time according to Onuegbu *et al*., 2007 [36] is affected by temperature, energy released, volume of heat and duration of heat application. When the external heat source is transferred to the wood material, the material increases in temperature as it receives and redistributes the heat formed and proceeded to the surface. Thus, as the temperature of the material increases, decomposition reaction occurs which releases combustible products. If sufficient heat is supplied, a combustible volatile mixture (pyrolysates) is formed and ignition occurs. The source of ignition is friction creating heat which acts upon chemical components causing combustion and finally flame [37].

The results of flame propagation rate of the timbers under investigation ranged between 0.09 and 0.25 gcm^{-1} as shown in the Table. The spread of a flame along a timber takes place in the following manner: piloted or radiant heat raises the temperature of a part of the timber to pyrolysis level. The resultant volatile and combustible pyrolysates ignite at the right air or oxygen concentration. Some of the exothermic heat of combustion is lost to the surrounding, while some part is re-channeled back for further pyrolysis of the substrate; hence, combustion is sustained. The rate of this pyrolysis/ combustion scheme along the timber determines the rate of flame propagation [38]. Flame propagation rate in all the samples are comparatively similar except in *D. oliveri* and *M. obovata* where the burning rate is higher and lower than in the fire-retardant treated wood respectively.

From Table 13, it is very clear that flame duration was highest in *D. regia* (45.00 seconds) and lowest in *D. oliveri* (7.00 seconds). Flame is a rapid free radical chain reaction of volatile materials with oxygen in the air. There are high concentrations of reactive species at flame temperature (1500^0C-3000^0C) [36]. At this flaming temperature, volatile products of timber materials ignite and fires result. Sustained combustion requires that gases be evolved at a rate equal to or exceeding the rate of flame propagation. Flame duration depends on fuel supply to the material, gasification of the fuel supplied and the volume of the mixture of the gaseous product with the oxygen in the presence of heat [39]. Flame duration in the FRTW is comparatively the same as in *V. doniana*, *T. grandis* and *D.guineense* but flame duration in *D. oliveri* is exceptionally lower than flame duration in the FRTW and exceptionally higher in *D. regia*. However, one observation which was unique was that the flame duration in all the respective samples was less than one minute.

After-glow time as shown in the Table was highest in *V. doniana* but lowest in *T. grandis*. Glow was defined by Price and co-workers in 1987 [40] as an exothermic surface reaction that radiates heat and light without a flame. It usually occurs in an abundance of oxygen and depends on unburned material as well as on char. After glow time compares favourably in both FRTW and the tropical timbers with the exception of *T. grandis, T. superba* and *I. gabonensis* that were comparatively small. All that can be stated however is that for all the timbers investigated, there are definite afterglow times, which in some instances last as long as three minutes and eight seconds but not more than four minutes.

The ash values of the FRTW and the ten woods as presented in Table 13 showed a low amount of ash yield at 1000^0C in the range 0.19 to 2.38% with *V. doniana* forming the highest amount of ash while both *D. guineense* and *M. obovata* yielded the least amount of ash. The low yields are due to the decomposition and dehydration at relatively high heating rate and at high temperatures while their differences are probably due to chemical factors, such as the minor components and inorganic compounds present. Ash formation in the FRTW was in similar range with those of *D. regia, A. indica, D. guineense* and *M. obovata* but ash formation in the other samples: *D. oliveri*, *V. doniana*, *T. grandis, N. laevis, T. superba* and *I. gabonensis* were in similar range greater than the former. The results were in agreement with those reported by Stadlmann and other researchers [41]. It is evident that under the condition of static air, thermal decomposition of wood proceeds through two different stages. The initial stage is attributed to the decomposition of primary cellulose resulting in the formation of combustible volatiles and the second, mainly involves dehydration leading to the formation of carbonaceous char that could lead to glowing combustion [42]. Brown [43] and Horrocks [44] reported similar findings in separate works that during pyrolysis at a low heating rate, there is less disruption of the carbon-to-carbon residues which condense into char, whereas fast pyrolysis at high temperatures tends to proceed much more violently with more disorderly disruption of chain structures to form flammable volatiles and with less condensation of carbonaceous entities to form ash.

Conclusion

The studies on flame properties of the tree species as contrasted to that of fire-retardant treated wood had shown that the trees investigated possess reduced flammability and are indeed fire tolerant. This property, though, partly attributable to evolution of special pyrolysates that are hardly combustible on heating is due to the presence of inorganic deposits in their cells. Hence, the trees could find applications in fire prone areas of human endeavour.

Acknowledgements: The authors acknowledge technical assistance of Messrs. Akwuba Mbazulike of Pharmacognosy and Traditional Medicine Department and Awopeju Abidemi of Statistics Department, both of Nnamdi Azikiwe University, Awka.

References

1. Momoh, M; Eboatu, A.N.; Horrocks, A.R.; Kolawole, E.G. (1996). Flammability of tropical woods – I. investigations of the burning parameters. Polym. Degrad. Stab. 48, 273-279.
2. Spurr, S.H.; Barnes, B.V. (1973). Forest-Ecology, 2nd edn., New York Ronald Press Co.
3. Eboatu, A.N. (1992). Fire, flammability and firefighting. Anchor Educational Publishers: Lagos, Nigeria, 1-13.
4. Federal Office of Statistics Publication, Nigeria 1985.
5. Fire Statistics UK, Home office, HMSO 1995.
6. Hall, J.R.; Cote, A.E. (1995). Fire Protection Handbook, 7th Edn, Donnelly and Sons, UK.
7. Hindersinn, R.R. (2009). Historical aspects of polymer fire retardance. Fire and Polymers. 425, 87-96.
8. Broido, A.; Kiltzer, F.J. (1963). A critique of the present state of knowledge of the mechanism of cellulose pyrolysis, Fire Res. Abst and Rev. 5 (2), 157-161.
9. Brow, F.L. (1970). Theories of the combustion of wood and its control. Forest Products Laboratory, Madison. Wisconsin.
10. Lopez-Beceiro, J.; Alvarez-Garcia, A.; Sebio-Punal, T.; Zaragoza-Fernandez, S.; Alvarez-Garcia, B.; Diaz-Diaz, A.; Janeiro, J.; Artga, R. (2016). Kinetics of thermal degradation of cellulose: analysis based on isothermal and linear heating data, Bio Res. 11 (3), 5870-5888.
11. Lipska, A.E.; Parker, W.J.J. (1966). Pyrolysis of the alpha-cellulose in the temperature range of 250-300 ^{o}C. J. Appl. Polym. Sci. 10 (10), 1439-1453.
12. Aggour, Y.A. (2000). Thermal decomposition of ethyl cellulose grafted copolymer in homogeneous media, J. Mat. Sci. 35 (7), 1623-1627.
13. Fang, J.B. (1966). Wood behaviour and fire-retardant treatment, a review of literature, Canadian Wood Council, Canada.
14. Reed-Walker, J. (1976). Pyrolysis of Polymers, Fire and Flammability series. Hilado, C.J., Eds., Technomire Publishing Co. Inc. Westpore Conn,13, 3-20.

15. Feng-Yuan, H. (2012). Thermal properties and thermal degradation of cellulose tri-stearate. Polymers. 4, 1012-1024.
16. Eboatu, A.N; Alhaji, S.M. (1995). Selecting the right trees for afforestation programme. Symp. on Chemistry and Biotechnology for National Development presented at Sheda Science and Technology Complex (SHESTCO).
17. Okonkwo, E.M.; Eboatu, A.N. (1999). Environmental Pollution and Degradation. Onis Excel Creations Ltd, Zaria, Nigeria. pp20-68.
18. Ikeagwu, K.I. (1997). Groundwork of research methods and procedures. Institute of Development Studies, University of Nigeria, Enugu Campus.
19. Obasi, I.N. (1999). Research methodology in political science. Academic Publishing Company. Enugu, Nigeria
20. Gupta, S.C. (2011). Fundamentals of Statistics. Himalaya Publishing House, Delhi, Mumbia.
21. Nwajiobi, C.C.; Eboatu, A.N; Odinma, S.C; Ezigbo, V.O. (2016). Effectiveness of ammonium chloride and borax in improving the fire retarding property of timber, Int. J. Sci. Tech. 5 (2), 77 - 80.
22. ASTM E84-Standard test method for Surface burning characteristics and building material. American Society for Testing and Materials, Philadelphia, PA.
23. Traux, T.R. (1956). Making wood fire retardant. Forest Service, U.S. Department of Agriculture. 1 - 11
24. Eboatu, A.N. Garba, B. (1990). Effect of flame retardant on the thermal behaviour of some tropical timbers. J. Appl. Polym. Sci. 39, 109 – 228.
25. Vines, R.G. (1968). Heat transfer through bark, and the resistance of trees to fire, Australian Journal of Botany. 16 (3), 499 – 514.
26. Vander-Weidel, B.L.; Hartnett, D.C. (2011). Fire resistance of tree species explains historical gallery forest community composition. For. Ecolo. Mgt. 178, 341 – 352.
27. Anonymous (1969). Building materials classification according to their behaviour during fire. Israel Standard 755.
28. Yashwanth, B.L.; Shotorban, B.; Mahalingam, S.; Lautenberger, C.W; Weise, D.R. (2016). A numerical investigation of the influence of radiation and moisture content on pyrolysis and ignition of a leaf-like fuel element. Combust. Flame. 163, 301-316.
29. Lewin, M.; Bello, S.B. (1975). Flame-retardant polymeric materials. Premium Press, NY.
30. Xin, S.; Yang, H.; Chen, Y.; Yang, M.; Chen, L.; Wang, X.; Chen, H. (2015). Chemical structure evolution of char during the pyrolysis of cellulose, J. Anal & Appl. Pyro. 116, 263-271.
31. Okoye, N.H.; Eboatu, A.N.; Arinze, R.U.; Ogbonna, O.A. (2014). Effect of density on flame characteristics of some tropical timbers, IOSR J. Appl. Chem. 7 (6), 104-111.
32. Okaor, V.N.; Obiadi, M. C.; Obiefuna, J. N. (2020). Correlations of Major Flame Characteristics of Some Fire Tolerant Trees in South-East Nigeria by Coefficient of Determination (R^2), Journal of Scientific Research and Reports, 26 (4); 81 – 98.
33. Dabale, A.; Ferguson, S.; Shotorban, B.; Mahalingam, S. (2013). Effects of distribution of bulk density and moisture content on shrub fires. Int. J. Wildland Fire. 22, 625-641.
34. Taras, M.A.; Saucier, J.R. (1967). Influence of extractives on specific gravity of southern pine, For Prod. J. 17, 97-99. `
35. Parham, R.A.; Gray, R.L. (1984). Advance in chemistry series 207 – the chemistry of wood. American Chemical Society, Washington, DC.

36. Onuegbu, T.U.; Eboatu, A.N.; Dioha, I.J. (2007). Reducing fire risks in recycled low-density polyethylene. Anachem Journal. 1 (1), 58-63.
37. Peters, N. (2000). Theoretical and numerical combustion. Cambridge University Press/John Wiley and Sons, Cambridge, UK.
38. Eboatu, A.N.; Atline, A.M. (1991). Studies on the thermal characteristics of some tropical woods. J. Renew. Ener. 2 (1), 49-53.
39. Babrauskas, V. (2003). Ignition Handbook, Fire Science Publishers, Issaquah, WA.
40. Price, D.; Horrocks, A.R.; Tuner, M. (1987). Flame retardants for cellulosic materials, Chemistry in Britain 235.
41. Stadlmann, K.; Klampfl, C.W.; Zemann, A.J. (2017). Influence of ionic additives on the pyrolysis behaviour of paper. American J. Analy Chem. 8, 774-791.
42. Mayer. Z.A. (2012). Comparative study on the pyrolysis of metal and ash-enriched wood and the combustion properties of the gained char. J. Analy. Appl. pyro. 96, 196-202.
43. Brown, F. L. (1970). Theories of the combustion of wood and its control. Forest Products Laboratory, Madison, Wisconsin.
44. Horrocks, A.R. (2013). Textile flammability research since 1980- personal challenges and partial solutions. Polym. Degrad. Stab. 98 (12), 2813-2824.