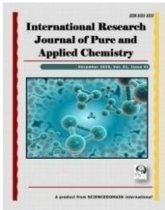

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The Effect of *Sterculia setigera* Del. Bark Extract on the Flammability of Flexible Polyurethane Foam

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Authors' contributions

This work was carried out in collaboration between all authors. Authors POI and UZF designed the study and wrote the protocol. Author BA preformed the statistical analysis, managed the literature search and wrote the first draft of the manuscript with assistance from author HMM. All authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

Fire retardant properties of the bark extract of *Sterculia setigera* on flexible polyurethane foam were investigated. The foam was treated with different concentrations of the extract and its flammability characteristics were compared with that of untreated sample. The result indicated increase in Ignition Time and Percentage Char with the increase in concentration of the incorporated extract while the Flame Propagation and After-Glow Time of the treated foam decreased with increase in concentration of the extract in the foam. The result revealed that the extract can significantly reduce the flammability of flexible polyurethane foam and serve to substantiate the local use of the plant in fire prevention by *Hausa* tribe.

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Keywords: Flame retardants; polyurethane; add on; ignition time; flame propagation rate; afterglow; char.

1. INTRODUCTION

Humans have always been plagued by unwanted fires, therefore it is not surprising that considerable efforts had been expended to investigate what makes objects burn, as well as how the flammability of materials could be controlled [1]. The method by which the flammability of polymers can be reduced by chemical means is of long-standing importance and has engaged the minds of scientists since the time of alchemy and the Roman era [2,3]. At the siege of Piraeus in 83 BC, for example, the wooden storming towers used were fire-retarded by treatment with alum. The ancient Egyptians also extensively practiced fire retardancy of cotton fabrics. The early scientists tried a variety of concoctions with the result that by the 19th century, enough knowledge had accumulated to enable Gay Lussac to make a systematic study of the phenomenon and to formulate theories [2,3,4,5]. These theories have since been widely accepted as laying the foundation for the understanding of the mechanism of flame retardancy in polymers. The first recorded effort at applying flame retardants to cellulose was in 1735 when a British patent was granted to Jonnathan Wyld for a flame retardant mixture consisting of borax, alum and sulphates [6,7]. Since then so much has been known that the burning behaviour of certain textile materials, papers, plastics and even timbers have been extensively investigated and documented. Nonetheless, it is necessary to state here that it is impossible to make such polymers as celluloses and the plastics completely flame-proof and still retain their advantageous qualities. In fact, for all polymers, it may require an exceptional ingenuity on the part of chemists to obtain the desired safety level and at the same time maintain the fundamental properties of the parent polymer. In most cases, flame retardant treatments aim at a compromise between safety and functional performance. In this article the effect of treating some flexible polyurethane foam materials with the extract of the bark of *Sterculia setigera* as flame retardant formulation was investigated.

S. setigera is a savanna tree. It is wide spread in the savanna area of tropical Africa, often characteristic of stony hills. It is deciduous and the bark is pale purplish, smooth with scales which when peeled off expose yellowish patches, exuding gummy sap. The leaves are broad and long, broadly ovate and densely pubescent on both surfaces. Flowers are borne in small inflorescence in the previous years shoots. The fruits are composed of 4 or 5 boat shaped carpels [8]. It is used in the treatment of asthma, bronchitis, cough, wound, boils, fever, cancer and dysentery. It is also used as a flame retardant [9]. It is used in the treatment of diarhoea [10]. According to Hausa folklore tradition it is used as a flame retardant.

The aim of this study is to develop novel plant based fire retardant for flexible polyurethane foam that is free from the shortcomings of the conventional flame retardants.

2. EXPERIMENTAL

2.1 Materials

2.1.1 Sample collection and identification

Two (2) kg of representative sample of *S. setigera* bark was collected, identified and authenticated at the Harbarium of the Botany unit, Usmanu Danfodiyo University, Sokoto, Nigeria.

The polyurethane foam materials comprised of a Polyether Polyol (polyoxyalkylene) with an initiator that has a functionality of 2. Their costs are cheaper than Polyester Polyols, resulting foams are hydrolysis resistant and the functionality and equivalent weights can be varied (ARCO Chemical Co.), TDI (toluene disocyanate) (KPX Fine Chemicals Co. Ltd, Korea), Methylene Chloride(BDH Chemicals Limited), Dimethylethylamine (Goldsmith A G), Tin (II) Isooctaoate (Evonik Goldschmidt GmbH) and Silicon Oil (Liberty Chemicals, London) were obtained from Concord Foam and Allied Chemicals Ltd opposite Sa'ad Petrol Station along western bye pass and Latex Foam Company in Rinjin Sambo industrial layout, all in Sokoto.

2.2 Method

2.2.1 Preliminary sample treatment

One (1) kg of the plant material was thoroughly washed with clean water, dried at room temperature and then powdered using a grinder.

A sample (200 g) of the powdered plant material was soaked in water (200 ml) for 48 hours. At the end of the extraction the extract was filtered using Whatman filter paper.The filterate was concentrated to dryness in an oven at 70ºC and stored until further use [9,10].

2.2.2 Sample preparation

2.2.2.1 Preliminary screening of fire retardant plants

Preliminary screening of the plant bark extract for flame retardancy was done by soaking the extract of this plant in commercial polyurethane foam obtained from Latex Foam Factory and its efficacy tested. Flame retardant activity was observed which prompted the final selection of this extract as a flame retardant in flexible polyurethane foam

2.2.2.2 Flexible polyurethane foam preparation

Flexible polyurethane foam was produced by mixing the TDI (2.5 ml) with the mixture of the polyol (12 ml), tin (II) isooctaoate (0.1 ml), silicon oil (0.2 ml), distilled water (0.5 ml) and dimethylethanalamine (0.1 ml). The mixture was thoroughly mixed with a glass stirrer to get a good dispersion of the reagents so as to get a foam which will be used as a blank sample in the experiment [7].

2.2.2.3 Incorporation of the plant extract in the foam production

Five series of different concentration (0.2, 0.4, 0.6, 0.8,1.0 g) of the plant extract (dried) were measured and incorporated into the above formulation as a monomer.The resultant foams produced were left to cure for 48 hours in order to get a foam of good cell structure.

2.2.3 Analysis

2.2.3.1 Add on %

The method adopted was the one in which the flexible polyurethane foams produced after inoculation with the flame retardant was weighed and the one without flame retardant was also weighed and the difference divided by the weight of the untreated foam multiplied by 100. The same dimension was used for all the samples, that is, 2 cm × 2 cm × 5 cm [4,5,6,11,12,13,14,]

2.2.3.2 After glow time

The after glow times were calculated using a stop watch to find out the time in seconds between the time the flame extinguished and the time the material stopped glowing [6,11,12,13,14].

2.2.3.3 Flame propagation rate

The time in seconds it takes the fire after being ignited to travel across the substrate were recorded and the flame propagation rate were calculated by dividing the distance which was 5cm by the time obtained using a stop watch clock [4,5,6,11,12,13,14].

2.2.3.4 Ignition time

The methodology adopted to find out the ignition time was achieved by recording the time in seconds after the Bunsen burner flame stroke the sample surface to the time when the sample caught fire [6,11].

2.2.3.5 Char formation

The methodology below was adopted to ascertain the amount of char formed. This was done by first crushing the sample in a crucible and weighing the content. It was then put in an electrically heated muffle furnace at 700ºC for 20 minutes and weighing the samples. It was calculated by dividing the weight of the material after burning by the weight of the material before burning multiplied by 100 [4,6,11,14].

3. RESULTS AND DISCUSSION

3.1 Results

The results of the various tests conducted are shown below from Figs. 1 to 5. These are add on %, ignition time, flame propagation rate, after glow time and char formation.

3.2 Discussion

The incorporation of flame retardant into a flexible polyurethane foam formulation can result to some extent in combustion modified urethane foams [15]. Addition of a flame retardant may also alter the rise time of the flexible polyurethane foam depending on the flame retardant type and the amount of the flame retardant used [15]. Furthermore, concentration of *S. setigera* bark extracts does not affect the rise time of the foams.

From Fig. 1 *Sterculia setigera* bark extract showed a moderate add on %. The lowest add on was 9% and the highest was 20%. Add on is directly proportional to the dope concentration of the flame retardant material and the specific gravity of the material. It is the amount of the flame retardant material imbibed by the substrate [11]. The result showed that add on % increases as the concentration of the dope increases in all the foams. This is in agreement with the cited literature[4] because they follow the same pattern despite the fact that the result varies which could be due to the difference in the dope concentration of the flame retardants used in both cases.

Fig. 2 depicted the ignition time of the extract. It had low ignition time yet it is higher than the blank sample. The lowest ignition time recorded in the series was 3 seconds and the highest was 7 seconds while that of the blank sample was 1 second. Moreover, the ignition time increases as the dope concentration increases in the subsequent concentrations. This is in concert with Ike, (2011).

Fig. 3 showed the flame propagation rate of the sample analysed. It had low flame propagation rate. The highest flame propagation rate recorded was 0.60 cm/s and the lowest was 0.70 cm/s while that of the blank sample was 0.98 cm/s indicating some flame retarding activity. There was also a decrease in the flammability resistance then an increase, finally decreasing as shown in the graph above. The spread of a flame along a substrate determines the rate of pyrolysis or combustion scheme [11].

The flame propagation rate is inversely proportional to flammability resistance of foams. If the flame propagation rate is increasing the flammability resistance is decreasing and vice versa. This assertion is true for the extract as the flame propagation rate decreases as the dope concentration increases along the series despite the fact that it burns vigorously with scattering of the burning material. The blank sample burn while dripping the burning portion continuously.

Fig. 4 showed the after glow times for the extract analysed. *Sterculia setigera* bark extract had an excellent after glow time. The lowest after glow time was 2 seconds and the highest was 6 seconds while the blank sample took 30 seconds before the glowing stopped. Glow is the light observed after the fire has been put out and depends on the amount of burnt material and oxygen available [6,11]. Therefore, it can be seen that the treatment decreases the after glow time as you go up the series. For all the materials investigated, there are definite after glow times.

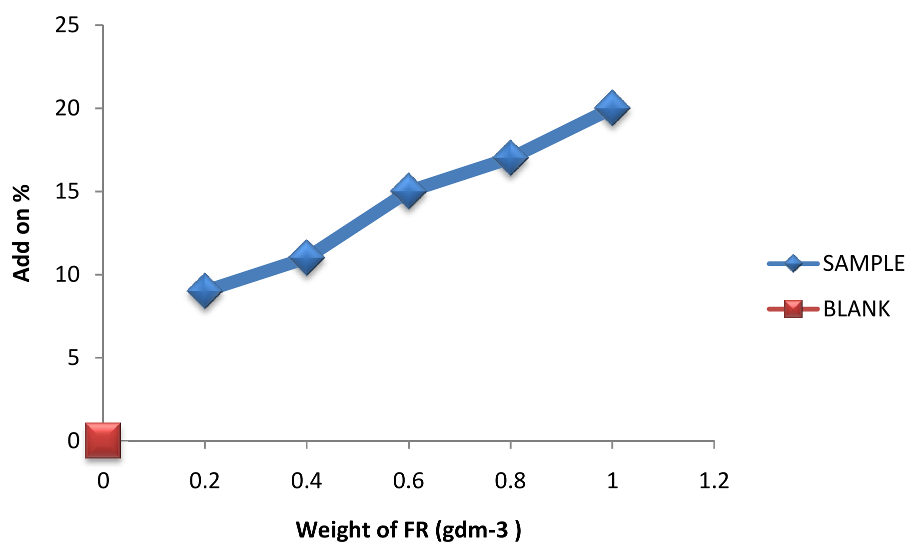

Fig. 1. Effect of concentration on add on

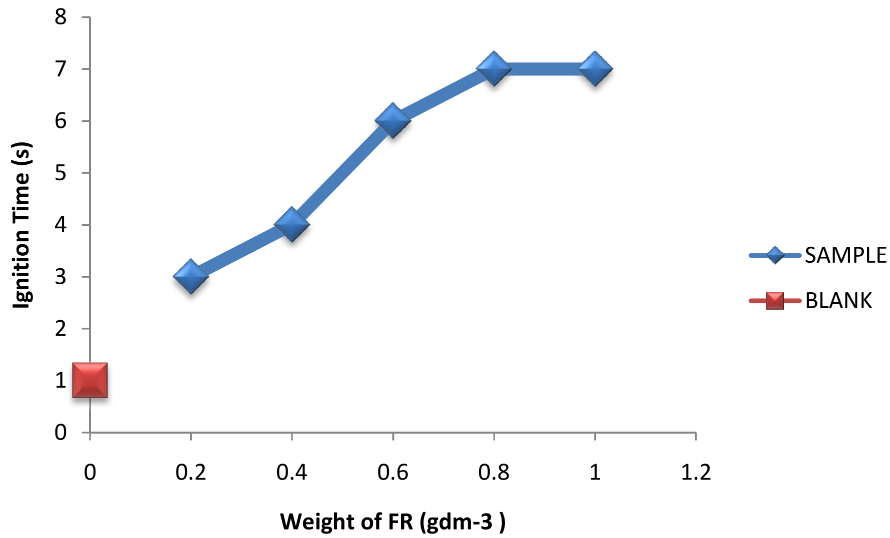

Fig. 2. Effect of concentration on ignition time

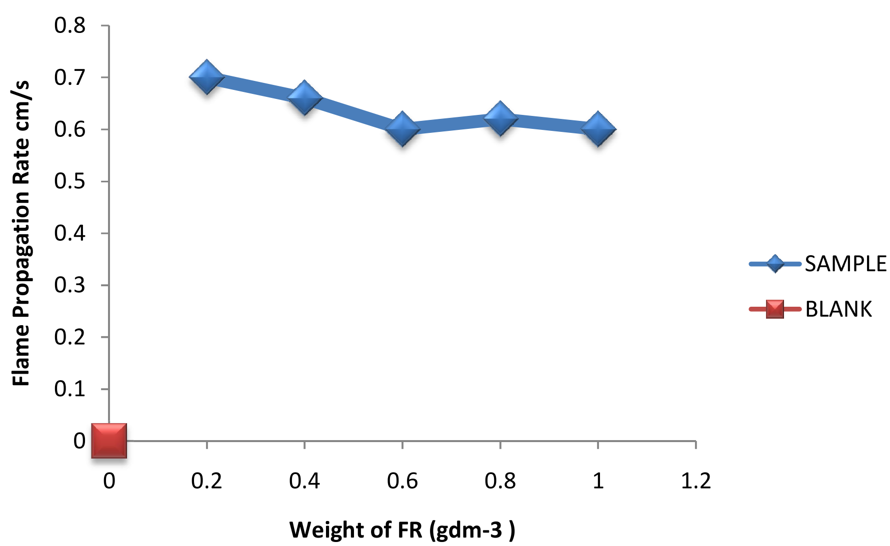

Fig. 3. Effect of concentration on flame propagation rate

Finally, Fig. 5 showed the char % of *Sterculia setigera* bark extract. It has a good char forming ability. The lowest char formation was 36% and the highest was 39%. The char formed by the blank sample was 10%. The char percentage increase initially as you go up the series then decrease and increasing again as you go along the series. Char formation is the formation of an impervious layer between the burning and the unburned part turning the material into a carbonaceous char. The formation of an insulating barrier between these parts is brought about by dehydrating agents or char forming agents which hinder heat transfer to unburned parts thereby reducing the reaction rate.

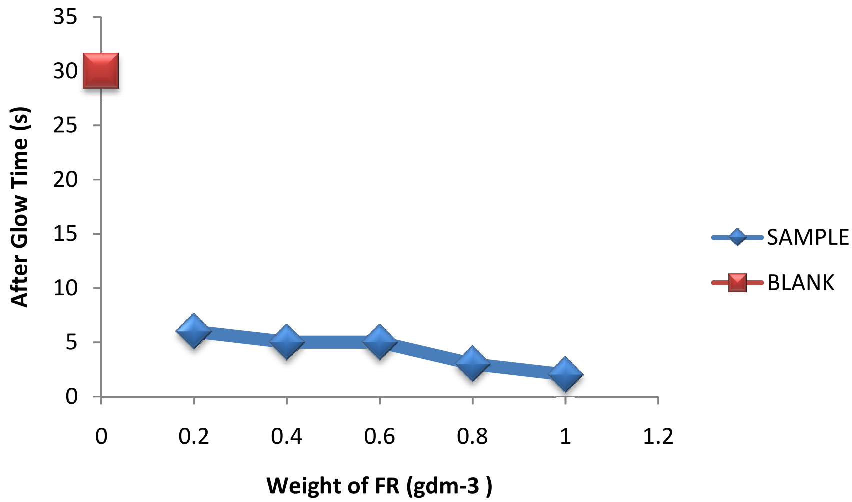

Fig. 4. Effect of concentration on after glow time

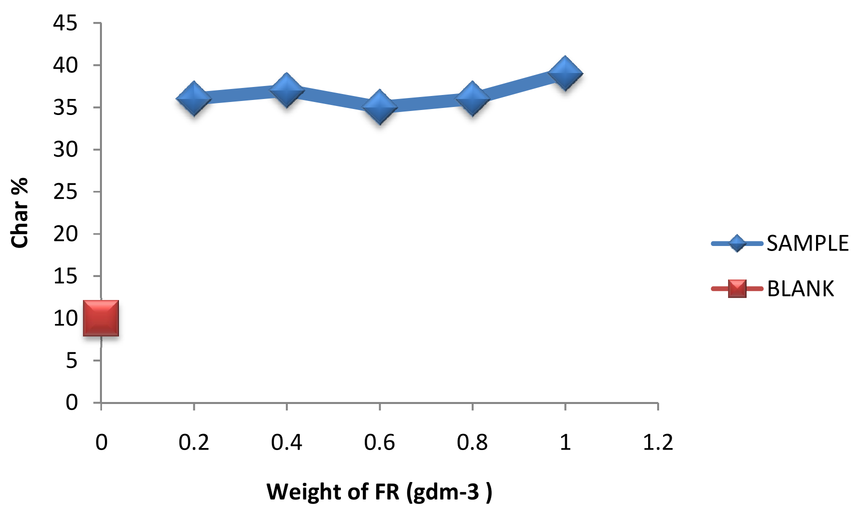

Fig. 5. Effect of concentration on char %

The difference in char percentage between the cited literature [7] and the present work is significant although it is higher than the blank sample which may indicate that the sample analysed has char forming ability.

4. CONCLUSION

The inoculation of flexible polyurethane foam with the extract of the bark of *S. setigera* modified the thermal properties of the foam. Therefore, it is envisaged that the devastation caused by fire on flexible polyurethane foam treated with *S. setigera* bark extract could be reduced. The result showed the effect of this treatment was more pronounced in after glow and char formation which may indicate condensed phase mechanism.

Flame suppressant treatment is aimed at delaying the spontaneous spread of the fire when it does occur, such that reasonable lives and properties may be saved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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