Asian Journal of Chemistry Vol. 19, No. 2 (2007), 1197-1201

Flame-Retardancy Studies on Cotton Fabric by Application of Aluminium Phosphate

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In the present study, the effect of synthetic aluminium phosphate on the flammability of cotton fabric (plain 240 g/m^2) has been reported. The suitable suspension of aluminium phosphate was prepared and each bunch of bone-dried, weighed fabrics had been dipped and stirred in the suspension baths. They were squeeze rolled and dried horizontally in an oven at 110ºC for 0.5 h. Afterwards the specimens were cooled in a desiccator and reweighed by an analytical balance. They were kept under ordinary conditions before the fulfillment of the vertical flame test. The optimum add-on values to impart flame and glow retardancy was about 30 g anhydrous aluminium phosphate per 100 g fabric. This action is assigned to be in favor of Condensed Phase Retardation ascribed in chemical theory. It is recommended to apply this salt in conjunction with other flame-retardants such as nitrogen compounds to gain a spectacular synergistic performance.

Key Words: Flame-retardancy, Aluminium phosphate, Condensed phase retardation, Chemical theory.

INTRODUCTION

The incorporation of flame-retardants into consumer products such as plastics, fibers, fabrics etc. has gained a great importance now-a-days.

A flame-retardant serves to slow down or to hinder the ignition or combustion of a material. However the material does not become non-combustible at any circumstances, but the flame-retarding component is intended to suppress a small fire from rapidly developing into a major disaster. Depending on their nature, flame-retardants may act chemically or physically in solid, liquid or gas phase. The interrupt the combustion during a particular stage of its process, *e.g.*, during ignition, heating, decomposition and flame spread[1].

The most important groups of chemicals applied as flame-retardants are: (1) Organic halogen compounds, mainly bromine and chlorine compounds, usually in conjunction with antimjony oxides, (2) Metal compounds such as alumina trihydrate, $Al_2O_3·3H_2O$ and magnesium hydroxide $Mg(OH)_2$ and (3) Phosphorus compounds; such as phosphate esters[2].

About 0.5 % of the production of phosphates in the world is used for flame proofing fabrics[3]. In recent years, the corresponding author has investigated the efficiency of different inorganic materials to be used as flame-retardants for cotton fabric etc. and the outcomes have been published in his thesis and several articles[4-14].

The purpose of this investigation is to search for the influential role of aluminium phosphate on the flame-retardancy imparted to cotton fabric. It is mentionable that $AlPO_4$ is obtained as a gelatinous precipitate on adding a solution of sodium phosphate to a neutral solution of an aluminium salt. The precipitate is soluble in mineral acids and also in excess of alkalis but not in dilute acetic acid or buffer solutions in qualitative analysis[15].

In the present investigation, aluminium phosphate as an insoluble salt, has been synthesized and applied *via* a suspension medium solution into cotton fabric and has been investigated for its impartation of flame-retardancy.

EXPERIMENTAL

A bath method treatment for precipitation of aluminium phosphate into the cotton fabric (plain construction weighing 240 g/m^2) is developed. The original specimens were unfinished 100% cotton, laundered and dried. The samples were 22 × 8 cm cut along the weft direction and pre-washed in hot distilled water. They were dried horizontally at 110ºC for 0.5 h in an oven, cooled in a desiccator and weighed in an analytical balance.

Bath treatment: With the exception of the first bunch, all other samples were impregnated with suitable concentrations of aluminium phosphate (at 22ºC) prepared as follows: 250 mL of Na_3PO_4 (2.5 M) was added into an equimolar $Al(NO_3)_3 \cdot 9H_2O$ solution. The gelatinous precipitate of $AlPO_4$ was filtered and rinsed with sufficient distilled water in order to remove the impurities, mainly $NaNO_3$. Afterwards the precipitate was dried and weighed and the suitable concentrations were made. Each bunch of fabrics had been diped and stirred into a suitable bath of aluminium phosphate suspension. Afterwards they were squeezed rolled and dried horizontally in an oven at 110ºC for 0.5 h. Then they were cooled in a desiccator, re-weighed with an analytical balance.

Flammability test: A vertical test method for the estimation of the fabric's combustibility has been studied on Mostashari's flammability tester. It is a rectangular aluminium frame cut on from one of its smaller sides. It has internal splits for inserting the fabric. The frame has also five even numbers of holes in each of its parallel legs so that pining of the fabric could be possible inside it.

The frame has two strips of 3 mm double sheet, 22.5 × 1.5 cm cut, perforated and welded at right angles to a shorter 9 cm strip. The sample conditions and environment were in average temperature ranged between 20 and 22ºC and the relative humidity of 65 ± 2%. The fabrics were conditioned overnight before the fulfillment of the flammability test. It is mentionable that all samples were pinned tightly to frame and held vertically in a retort stand by clams with the lower edge 1.9 cm above top of a Bunsen burner with a three centimeter yellow flame. The ignition time was 3 s. This procedure was conducted in order to avoid the harsh circumstances of ignition. The accuracy of the burning time was determined close to the nearest 0.1 s with a stopwatch for all of the specimens. The flammability test was conducted in a put out fume-cupboard before the accomplishment of the experiment. However the exhaust ventilator had been turned on for about 5 min, after each burning.

RESULTS AND DISCUSSION

The experimental results are listed in Table-1. Vertical flame test was carefully conducted to ascertain the add-on values on the subject of the burning times in seconds.

The burning rates are calculated by means of dividing the length of the specimens (22 cm) by the burning times (in sec). The states of the specimens after the fulfillment of tests are given. It can be deduced from the experimental results that the efficient quantities of anhydrous aluminium phosphate expressed in g per 100 g dried fabric to impart flame-retardancy is about 30 %. Althrough aluminium phosphate has considerable phosphorus content; but showed only a tendency towards flame-retardancy.

It can be attributed from the results of the third row that inadequate amounts of aluminium phosphate *i.e.* about 17 % of it decreased the burning time and increased the burning rate of the treated specimens. The results are similar to the work of Reeves and Hammons[16]. They notified that inefficient quantities of certain flame-retardants accelerate the burning rates of fabrics, *i.e.* by using inadequate amounts of some flame-retardants an imperfect rapid combustion deformation occurs and a decrease in burning duration and increase in burning rate is the resultant. This can be also generalized for the action of various flame-retardants including inadequate amounts of aluminium phosphate deposited into cotton fabric. The experimental observations indicated that the black carbonaceous texture remained after the combustion process of treated fabric with low add-ons of aluminium phosphate has been accomplished. In the mean time the burning characteristics of the treated specimens also showed suitable efficiency in prevention of after-glow. It appears that this behavior is in favour of chemical theory explained by Little[17]. This theory supports that some flame and glow retardants promote the formation of solid char rather than volatile pyrolysis fragments when the polymer is subjected to thermal decomposition, then the degradation could occur *via* a catalytic dehydration shown below:

$$(C_6H_{10}O_5)_x \rightarrow 6xC + 5xH_2O$$

TABLE-1
EFFECT OF DEPOSITED SYNTHETIC ALUMINIUM PHOSPHATE ON THE FLAME-RETARDANCY IMPARTED TO COTTON FABRIC (PLAIN 240 g/m^2)

Set*	Treating suspension solution, formalities	Per cent (add-on) drying at 110ºC and weighing	Burning time (s)	Burning rate (cm/s) (interval)	State of the fabric**
A	Untreated	---	34.66	0.63	CB
B	1.5	16.90	28.50	0.77	CB
C	2.0	30.14	---	---	FR
D***	2.5	39.96	---	---	FR

*Average of 5 tests of each set.
**CB = completely burned and FR = flame-retarded.
***Confirmatory tests applying excessive quantities of the additive.

Some explanations are given by several researches *e.g.* Troitzch[18] stated that phosphorus contianing flame-retardants mainly influence reaction taking place in the condensed phase[19]. They are particularly efficient in materials with high oxy-content compounds, such as oxygen containing plastics and cellulose. They are converted to phosphoric acid by thermal decomposition which extracts water from the pyrolysing substrate in the condensed phase, causing it to char, *i.e.*: the phosphoric acid formed, esterifies and dehydrates the oxygen-containing polymer and causes charring. However the suggestion of Jolles and Jolles[20] indicated that phosphorus compounds forms phosphoric acid on heating which coats the surface of the polymer as a stable coating material and causes it to become a carbonaceous residue.

Conclusion

Aluminium phosphate as a phosphorus-containing compound deposited into cotton fabric showed a tendency towards flame and glow-retardancy. This behaviour is assigned to its multiple physico-chemical characteristics, which comply with different flame and glow-proofing theories including coating theory and also condensed phase retardation ascribed in chemical theory. This chemical may be converted to phosphoric acid by thermal decomposition, which extract water from the pyrolysing substrate, causing it to a carbonaceous residue called “char”. The observation concerning the formation of a strong and thick black carbonaceous residue supports this hypothesis.

The optimum add-on values to impart flame and glow retardancy into the cotton fabric was about 30 g anhydrous aluminium phosphate per 100 g cotton fabric. It may be recommended to use this salt in conjunction with other flame-retardants such as nitrogen compounds to gain a better manifestation. On the other hand the above-mentioned salt, as a non-durable additive and also its relatively high deposition, would affect the fabric's handle aesthetic and mechanical properties. Therefore it can not be recommended for using in garments. Instead of this the obtained results may be used, for other commercial applications, such as insulators, plastics and polymers, etc.

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(*Received*: 6 December 2005; *Accepted*: 8 September 2006) AJC-5076