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Burning of Cotton Fabric Impregnated by Dipotassium Hydrogen Phosphate as a Flame Retardant

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The effect of dipotassium hydrogen phosphate as a non-durable finish on the flammability of 100 % cotton fabric, woven construction, weighing 160 g/m^2 has been of interest in this study. The launched bone-dried, weighed fabrics were impregnated with suitable concentrations of aqueous dipotassium hydrogen phosphate solutions by means of squeeze rolls and dried at 110ºC for 0.5 h. Afterwards, they were cooled in a desiccator, re-weighed with an analytical precision and kept under ordinary conditions before the fulfillment of the vertical flame test. The optimum add-on value to impart flame retardancy expressed in g anhydrous dipotassium hydrogen phosphate per 100 g fabric was about 17.88 %. The results obtained comply with Coating theory and Chemical theory and also Condensed phase retardation.

Key Words: Flammability, Dipotassium hydrogen phosphate, Flame-retardancy, Condensed phase retardation.

INTRODUCTION

Now-a-days, flame-retarded substances are considered to be very important in the prevention and control of fires. They are found in building materials, carpets, curtains, bedding, baby clothes, electrical appliances, computer cases and numerous of the other products[1]. A flame-retardant is a component or mixture of compounds that when added or incorporated chemically into a polymer serves to show up to hinder the ignition or growth of fire[2,3]. It is mentionable that the flame-retarding component is intended to prevent a small fire from rapidly developing into a major disaster[1]. The term flame-retardant is often used within the context of combustible synthetic or natural polymers. However a flame-retarded substance is believed to be combustible in the intense ignition circumstances. There are several ways in which flame-retardants may work. As a rule flame-retardant interferes with one or more of the three factors essential to the combustion process, in other words, it interrupts the fire triangle[2] *i.e.* combination of oxygen, fuel and heat. In practice, flame-retardants are tailored to the specific properties of the flammable material and to the common causes of fire in the materials environment. The most important groups of chemicals used in the world as flame-retardants are: (1) organic halogen compounds, especially bromine and chlorine compounds, often in combination with antimony oxides (almost half the market volume in dollars), (2) phosphorus compounds, such as phosphate esters (*ca.* 20 %) and (3) metal compounds such as alumina trihydrate ($Al_2O_3{\cdot}3H_2O$) and magnesium hydroxide[1] (another 20 %).

It is noticeable that the value of chemicals sold for use as flame-retardants in Europe in 2003 was forecasted the split of income between the three main categories. The halogen-based organics 26 %. Inorganic compounds including $Mg(OH)_2$, $ZnSnO_3$, Sb_2O_3 and borates 36 % and phosphorus-based chemicals[4,5] 38 %.

The aim of this study is to investigate the effect of deposited dipotassium hydrogen phosphate as a nondurable finish for the impartation of flame-retardancy to cotton fabric.

EXPERIMENTAL

All fabrics were woven construction, weighing 160 g/m^2, unfinished 100% cotton, laundered and dried. They were cut into 22 × 8 cm strips along the warp direction and pre-washed in hot distilled water. The specimens were dried at 110ºC for 0.5 h in a oven, cooled in a desiccator and weighed with analytical precision.

Bath treatment: With the exception of the first bunch, all other samples were impregnated with suitable concentrations of dipotassium hydrogen phosphate at 20ºC. Afterwards, they were squeeze rolled and dried horizontally in an oven at 110ºC for 0.5 h and then they were cooled in a desiccator and re-weighed with an analytical balance so that the suitable add-on presented into the specimens were obtained. The treated fabrics were kept over night under ordinary conditions before the fulfillment of the flammability test, so that the humidity regain obtain during this period.

Flammability test: A vertical flammability test method similar to the procedure described in DOC FF3-77[6] was used. The conditions of the samples and environment were in average temperature ranged between 20 and 22ºC and the average of relative humidity ranged 65 and 67 %. The aforementioned tester is an aluminium frame: two strips of 3 mm aluminium double-sheet, 22.5 × 1.5 cm were cut, perforated and welded at right angles to a shorter 9 cm strip. The samples were pinned tightly to the frame and held vertically in a retort stand by clamps with the lower edge 1.9 cm above the top of the three centimeter yellow flame of a Bunsen burner so that the harsh ignition circumstances is avoided. The procedure and other details were also described in the previous published articles[7-17]. Repeatability of burning time was ± 5 % for untreated specimens. The figure for salt treated fabrics was much lower. In fact the pad squeeze process is known to give a certain amount of variability. After an ignition time of 3 s at the bottom edge, the total burning time was measured with a stopwatch at the nearest 0.1 s. The char length was measured to the nearest centimeter. It is mentionable that the iginition time was subtracted from the total combustion duration and then the rest was reported as the burning time. The flammability test was conducted in a put out fume-cupboard prior the fulfillment of the combustion. However the exhaust ventilator had been turned on for about 5 min, after each burning, so that the consumed toxic gases were conducted away from the environment and fresh air could enter around the experimental apparatus.

The experiment results are listed synoptically in Table-1. Vertical flame test was carefully conducted to ascertain in add- on values on the subject of the burning times in s (column 4). In column 5 the burning rates are calculated by means of dividing the length of the specimens (22 cm) by the burning times (s). In column 7 the states of the fabrics after the fulfillment of the tests are given. It can be attributed from the above mentioned experimental results that about of 17.88 %, dipotassium hydrogen phosphate is efficient to impart flame-retardancy to the fabric. The burning characteristics of the treated samples indicated suitable effectiveness in suppressing the after glow *i.e.* the flame-less combustion was not experimented[2]. The plausible mechanism of such flame and glow retardancy can be justified by the chemical theory stated by little[18]. This theory inidcates that the action of certain flame and glow retardants is to promote the formation of solid char rather than volatile pyrolysis products when the polymer is subjected to thermal degradation. Ideally the carbon present in cellulose could be confined to the solid products and water vapour. Hence the decomposition could be pushed through the catalytic dehydration shown below:

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

In this regard, Jolles and Jolles[19] stated that phosphorous compounds form phosphoric acid during the combustion process. Afterwards, form a polymeric meta-phosphoric acid on heating, which is a stable coating material and coats the surface of the polymer as a carbonaceous residue. It is mentionable that Troitzach[20] stated that phosphorous containing flame-retardants mainly influence the reaction, which occurs in the condensed phase. They are particularly efficient in materials with high oxy-content, such as oxygen containing plastics and cellulose. The are converted by thermal degradation to phosphoric acid which in the condensed phase, extracts water from the pyrolyzing substrate, causing it to char *i.e.* the phosphoric acid formed, esterifies and dehydrates the oxygen-containing polymer and causes charring.

TABLE-1
EFFECT OF DEPOSITED DIPOTASSIUM HYDROGEN PHOSPHATE ON THE FLAME-RETARDANCY IMPARTED TO COTTON FABRIC (WOVEN CONSTRUCTION WEIGHING 160 g/m^2)

Set No.*	Treating with solution of K_2HPO_4 (M)	Per cent (add-on) drying at 110ºC and weighing	Burning times (s)	Burning rate (cm/s)	Char length (cm)	State** of the fabric
1	Untreated	-	30.0	0.733	-	CB
2	0.15	3.77	19.0	1.157	-	CB
3	0.20	6.32	12.7	1.377	17.5	PB
4	0.25	7.72	9.0	1.666	15.0	PB
5	0.30	8.83	7.0	1.486	10.4	PB
6	0.40	10.40	735.6	0.030	-	SC***
7	0.50	12.56	768.4	0.029	-	SC
8	0.75	17.89	-	-	-	FR

*Average of 5 tests of each set, **CB = completely burnt, PB = partially burnt, SC = slow, FR = flame retarded and ***Flame-less combustion continued.

Conclusion

Dipotassium hydrogen phosphate deposited into to the cotton fabric to impart flame and glow-retardancy demonstrated a tendency towards these phenomena. This behaviour is assigned to its multiple physico-chemical characteristics, which comply with different flame and glow-proofing theories including chemical theory, coating theory and condensed phase retardatin. The optimum add-on values to impart flame and glow retardancy was about 17.88 g anhydrous dipotassium hydrogen phosphate per 100 g fabric. It may be recommended to use the above mentioned salt in conjunction with other flame-retardants such as nitrogen compounds to gain a better manifestation on the flame-retardancy. The synergistic effect may be beneficial to improve the afore-mentioned performance. On the other hand the above-mentioned salt as an nondurable additive and also its relatively high deposition, into the fabric will affect its handle aesthetic and mechanical properties of the fabric. Therefore, it cannot be recommended to be used for garments. However, choosing cotton fabric as polymeric substrate could be beneficial for a reliable and economical detection of organic and inorganic flame-retardants. Furthermore their synergism may also be detected. Ultimately the obtained results may be used for other commercial applications, such as insulators, plastics and polymers, *etc*.

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