JOURNAL OF Applied Polymer SCIENCE

Effect of Chicken-Feather Protein-Based Flame Retardant on Flame Retarding Performance of Cotton Fabric

Xueyan Wang, Changqin Lu, Chenxiao Chen
School of Textile and Material, Xi'an Polytechnic University, Xi'an, 710048, People's Republic of China
Correspondence to: X. Wang (E-mail: wangxueyan815@126.com)

ABSTRACT: A new kind of eco-friendly chicken-feather protein-based phosphorus–nitrogen-containing flame retardant was synthesized successfully with chicken-feather protein, melamine, sodium pyrophosphate, and glyoxal. And its structure was characterized by Fourier transform infrared spectroscopy, and the thermogravimetry of the agent was analyzed. Then the flame retarding performances of the chicken-feather protein-based flame retardant and in combination with the borax and boric acid in application to a woven cotton fabric were investigated by the vertical flammability test and limited oxygen index test. In addition, the surface morphologies of the treated and untreated fabrics were conducted by the scanning electron micrographs (SEM), and the thermogravimetric analyses of the treated and untreated cotton were explored, and the surface morphologies of char areas of the treated and untreated fabrics after burnt were tested by the SEM. The results showed that the flame retardancy of the cotton fabric treated by the chicken-feather protein-based flame retardant in combination with borax and boric acid was improved further, and the combination of the chicken-feather protein-based flame retardant and borax and boric acid could facilitate to form a homogenous and compact intumescing char layer, and the combination of them plays a good synergistic effect in the improvement of the flame retardancy of the treated cotton fabric. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2014**, *131*, 40584.

KEYWORDS: chicken-feather; flame retardance; proteins; textiles; thermal properties

Received 26 March 2013; accepted 9 February 2014
DOI: 10.1002/app.40584

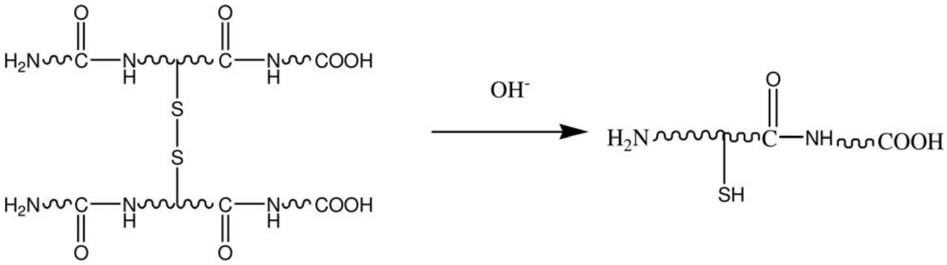
INTRODUCTION

Fire resistance of many articles for daily use is in great demand to prevent fire hazards.[1] Halogenated flame retardant has good fire-retardant effectiveness, which is one of the important flame-retardant agent, but it is not beneficial to the environment.[2,3] Currently, the use of halogenated flame retardant is being limited and halogen-free alternatives are being developed rapidly due to the increasing demand of environmentally friendly alternatives. Phosphorus–nitrogen inflating flame retardant emits less smoke, and poisonous and corrosive gas, preventing molten dropping and its high efficiency in flame retarding makes it ideal for the use in textile fabrics.[4–10] Chicken feather, which is a biodegradable material, is abandoned in large amounts throughout the world every year, if the waste protein could be used as a valuable resource, it could not only turn waste to treasure, but also reduce environmental pollution. It has been reported in many studies in relation to the application of the wasted chicken feather.[11–14] Bosco and his colleagues applied whey protein that acted as an agent to treat cotton fabric; they also assessed the effect of protein on the thermal and thermo-oxidative stability and on flame retardant properties of the treated cotton. The results showed that the burning rate decreased and the final residues increased when the treated cotton was heated and burn.[15] However, very little research has been conducted to study the chicken-feather protein-based flame retardant. Chicken-feather keratin is inherently less flammable due to the presence of high doses of nitrogen element within its molecular structures.[16] So using chicken-feather protein as a raw material, which acts as nitrogen provider, and in combination with other flame retarding monomers (e.g., melamine and sodium pyrophosphate, which act as nitrogen provider and phosphorus provider, respectively) and a cross-linking agent (e.g., glyoxal) would possibly develop a new kind of biological environmentally friendly P–N flame retardant to enhance the flame retarding property of the treated cotton fabric; thus it could not only replace the halogenated flame retardants, reduce pollution and save cost, but also could change waste into treasure. On this basis, the objective of this study was to explore the effect of the novel chicken-feather protein-based P–N flame retardant and in combination with borax and boric acid on the flame retardancy of the finished woven cotton fabric and to elucidate the flame-retardant mechanism.

EXPERIMENTAL

Materials and Instruments

Desized and scoured and bleached plain woven cotton fabric used for this study was provided by the YOUNGOR Co., Ltd.



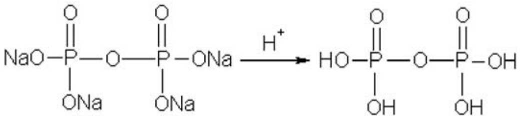
Scheme 1. Broken reactions of the disulfide linkages in the chicken-feather keratin. *The left is chicken-feather keratin; and the right is a degraded chicken-feather keratin molecular.

(Zhejiang, China). Its specification is as follows—Ends/cm: 60, picks/cm: 60, warp count: 20 s, and weft count: 20 s. Chicken feather was collected from a slaughterhouse (Xi'an, China). All other reagents were of analytical grade and were purchased from Xi'an Chemical Reagent Co., Ltd. (Xi'an, China). LA-205 laboratory tester was made by UENOYAMA KIKO Co., Ltd. (Kyoto Japan). YG (B) 815D-I flammability tester was made by Wenzhou Darong Textile Instruments Co., Ltd. (Zhejiang, China). LFY-605 automatic oxygen index instrument was made by Shandong Textile Science Research Institute (Shandong, China). NEXUS870 infrared spectrogram instrument was made by Nicolet Thermo Instruments Co., Ltd. (Canada). S-2700 scanning electron microscope (SEM) was made by HITACHI Instrument Co., Ltd. (Japan). METTLER TOLEDD type thermal gravimetric analysis instrument was made by Switzerland.

Preparation of Chicken-Feather Keratin Agent

According to Saravanan's study, the amino acid sequence of a chicken feather is very similar to that of other feathers and also has a great deal in common with reptilian keratins from claws regardless of the chicken-feather type.[16] In our experiment, the chicken-feather was collected from a slaughterhouse. Then, the collected chicken-feather was cleared and dissolved and degraded with a solution containing 10 g/L of NaOH and 4 g/L of urea at 90°C for 3 hours, and the rate of solid to liquid was 1 : 20. The disulfide bonds in the chicken-feather keratin broke (shown in Scheme 1) and some disulfide bonds decomposed and released H_2S, and at the same time, the peptide bonds in the chicken-feather keratin were hydrolyzed in the dissolved process.

Next, the dissolved chicken-feather keratin solution was neutralized with hydrochloric acid until neutral and filtered. The filtrate was treated with hydrochloric acid to precipitate the dissolved protein (the pH value of the protein solution was adjusted to about 4, which is near to the isoelectric point of the protein). At last, the protein precipitate was obtained by filtering again, and dried at 50°C. The part of the broken disulfide bonds in the peptide chain of the dissolved chicken-feather keratin were established again in this process. The yield drying chicken-feather keratin agent was ground to powder and readied to use as one of the reaction substrates for synthesis of the chicken-feather protein-based P–N flame retardant.

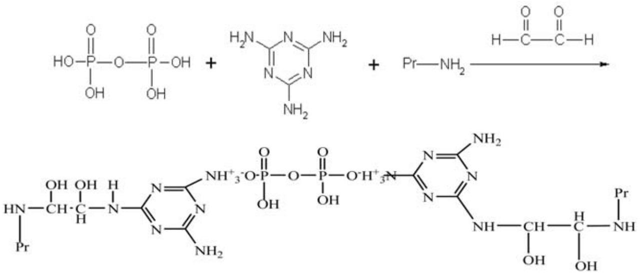


Scheme 2. The reaction of sodium pyrophosphate and acid.

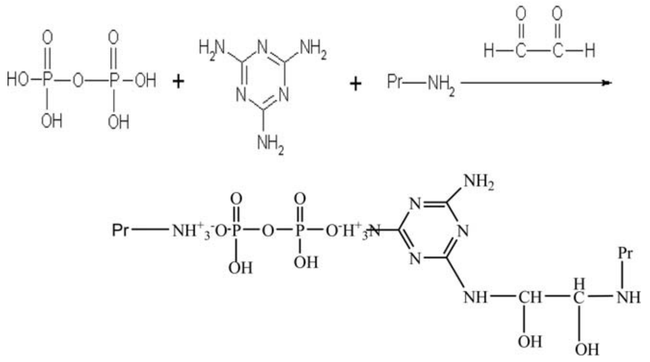
Preparation of the Chicken-Feather Protein-Based P–N Flame Retardant

A certain amount of melamine, sodium pyrophosphate, and chicken-feather keratin powder (the mass rate is 1 : 8 : 5) dissolved in distilled water was added to a 250 mL three-necked round-bottomed glass flask equipped with a constant-voltage dropping funnel and a thermometer. The reaction mixtures were dispersed and dissolved in stirring at room temperature for 2 hours with a heat-up magnetic agitator, then a certain amount of glyoxal (180% on the mass of the chicken-feather keratin powder) was added dropwise into the flask and the reactive bath was heated to 80°C and held at the temperature for 4 hours, keeping the pH value about 5. At last, the pH of the solution was adjusted to 8, and the reactive bath was raised to 90°C and held at this temperature for 2 hours. The yellowish chicken-feather protein-based P–N flame retardant was obtained. The reaction formulae are explained in Schemes 2, 3, and 4.

Here, *Pr-NH*$_2$ represents a dissolved chicken-feather keratin molecule, which contains many hydrophilic polar groups, such as amino groups, hydroxyl groups, and sulfhydryl groups. These groups are able to react with glyoxal through its aldehyde group and are able to react with pyrophosphate. And melamine, which contains many amino groups, can also react with glyoxal through its aldehyde group and can react with pyrophosphate. There, glyoxal acted as a crosslinking agent that could crosslink with the chicken-feather keratin-containing compounds and the melamine-containing compounds. So resultants were a mixture of several flame retardants, which are beneficial to improve the



Scheme 3. One of reactions of synthesized chicken-feather protein-based P–N flame retardant.



Scheme 4. Another reaction of synthesized chicken-feather protein-based P–N flame retardant.

flame retardancy of the finished cotton with these agents (containing flame-retardant elements). Therefore, the resultants were obtained without additional purification. The rate of containing solid of the agent was 22.8%.

Flame-Retardant Treatment

Cotton fabrics were first immersed with different compositions of finishing agents as shown in Table I, and dipping at 90°C for 15 min, then passed through a laboratory padder with two dips and two nips, the wet pick-up of the fabric was approximately 75%. After treatment, the fabrics were dried at 90°C for 3 min and cured at 140°C for 3 min in a LA-205 laboratory tester without subsequent washing.

Measurement of Targets

Fourier Transform Infrared Spectroscopy (FTIR) Measurement. The FTIR spectra of the chicken-feather protein and the chicken-feather protein-based flame retardant were recorded on a NEXUS870 infrared spectrogram instrument with the KBr pellet technique. The KBr pellets were prepared by the grinding of one part of the sample with nine parts of spectral-grade KBr and pressing in an evacuated die under suitable pressure to get pellets.

Vertical Flammability Test. The vertical flammability of the treated and untreated fabrics were measured using a YG(B)815D-I flammability tester according to the Chinese standard of GBIT5455-1997 test of "The flammability test of textiles with the vertical burning experiment." The samples with the measurement of 30 cm × 8 cm were held by tweezers and suspended approximately 1 in. directly above a Bunsen burner flame for 12 s to cause ignition and combustion, and then the flame was removed and the burning time and burning characteristics were recorded. Each sample was tested five times under air atmosphere.

Limited Oxygen Index (LOI) Test. The LOI of the treated and untreated fabrics were measured using a LFY-605 automatic oxygen index instrument according to the Chinese standard of GB/T5454-1997 test of "The flammability test of textiles with the oxygen index method."

SEM Measurement. After spurted with gold under vacuum, the surface morphological structures of unburned samples and burned residual char layer of treated and untreated fabrics were examined by an S-2700 SEM, with an accelerating voltage of 20 kV and a current of 10 μA at a high magnification power of up to 2000×.

Table I. The Constituents of the Flame-Retardant Finishing Bath

Name of agent	1#	2#	3#	4#
P-N flame retardant agent (g/L)	250	0	250	0
Borax (g/L)	0	10	10	0
Boric acid (g/L)	0	60	60	0

Thermal Gravimetric Analysis (TGA). TGA of the flame retardant, the treated and untreated cotton fabrics were determined using a METTLER TOLEDD type TGA instrument, respectively. All of the specimens were monitored at a heating rate of 10°C/min from room temperature (20°C) up to 1000°C. The process went along in the protection of high pure nitrogen. Before measured, the measuring specimens were scratched by a razor blade, so that their pulverization could be achievable.

RESULTS AND DISCUSSION

Characterization of the Structure of the Chicken-Feather Protein-Based Flame Retardant

The IR spectra of the chicken-feather keratin agent and the chicken-feather protein-based P–N flame retardant represented in Figure 1 shows that there is an intense absorption band at 3400 cm^{-1} nearby, which is primarily due to the N—H stretching vibration. Absorption peak at 1650 cm^{-1} nearby, primarily governed by the stretching vibration of the C═O (70%–85%) and C—N bonds (10%–20%), is the characteristic absorption peak of amide I. Absorption peak at 1560 cm^{-1} nearby is the characteristic absorbing peak of amide II mainly deriving from the in-plane N—H bending. The peak at 1410 cm^{-1} nearby is associated with the amide III band. So it confirms the presence of protein structure in the chicken-feather keratin agent and in the chicken-feather protein-based flame retardant prepared by us. From Figure 1 it also can be seen that the chicken-feather protein-based

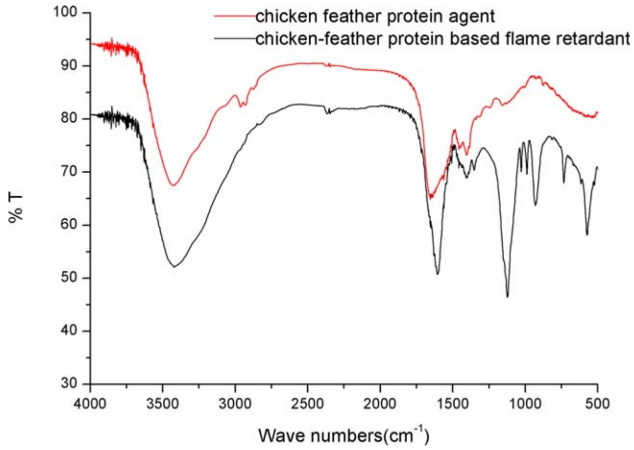


Figure 1. The infrared spectra of the chicken-feather protein and the chicken-feather protein-based flame retardant. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

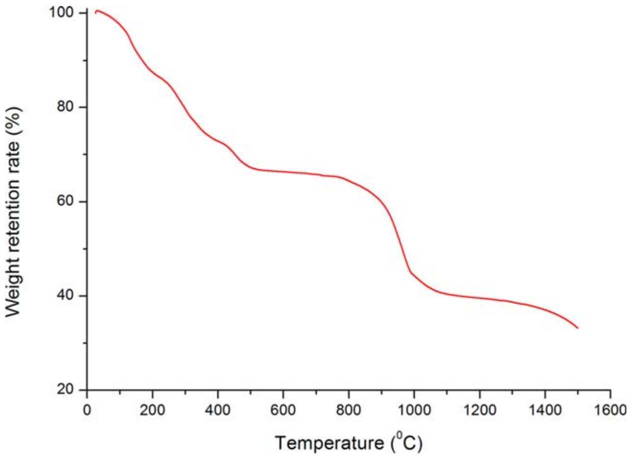


Figure 2. TGA diagram of the chicken-feather protein-based P–N flame retardant. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

flame retardant forms new bands at 1123.4, 1028.9, 988.9, 734.0, and 575.5 cm^{-1}, which are attributed to the characteristic absorption peaks of P=O, P—O—P and P—O, respectively, indicating that the synthesized flame retardant is the chicken-feather protein-based P–N-containing flame retardant.

TGA of the Chicken-Feather Protein-Based Flame Retardant

Thermal property of the synthesized flame retardant was tested by TGA. Figure 2 is the TGA curve of the chicken-feather protein-based P–N flame retardant, and the thermal data are represented in Table II. It is observed that the decomposition of the agent consists of four stages of weight loss. The first stage of decomposition of the chicken-feather protein-based P-N flame retardant lies between 115.11°C and 164.93°C, during which about 10% of weight is lost. The second stage of decomposition occurs in the ranges of 254.97°C–319.16°C, and the rate of weight loss of the stage is about 13%. About 9% weight loss is observed during the third stage of decomposition in the range of 254.97°C–319.16°C. The area of the most violent degradation takes place in the ranges of 894.95°C–987.42°C, and the rate of weight loss of this stage is about 24.42%. From Figure 2, it can be also seen that about 40% of solid residue is left at 1000°C, and weight retention rate is about 33.20% at 1500°C. So the experimental results showed that the synthesized chicken-feather protein-based flame retardant has high thermal stability and excellent char-forming ability. Because the chicken-feather protein-based flame-retardant was synthesized with chicken-feather protein, melamine, sodium pyrophosphate, and glyoxal, the thermal stability and char-forming ability of the synthesized agent was compared with that of the melamine pyrophosphate (MPP), which is one of the widely used commercially available flame retardants. The solid residue of the chicken-feather protein-based P–N flame retardant is much higher than that of MPP. The weight retention rate is only about 30.2% at 800°C for MPP.[17] The high thermal stability and excellent char-forming ability of the chicken-feather protein-based P-N flame retardant may be due to its structure, which contains many hydrophilic polar groups, such as amino groups, hydroxyl groups, and carboxyl groups, etc., so the synthesized flame retardant can act as a complex of acid source, and carbonization agent, lead to inhibiting decomposition at higher temperature. The high residue of char forming is beneficial to increase the flame retardance.[18] So it is indicated that the chicken-feather based P–N flame retardant is more helpful for enhancement of flame retardance of cotton than that of MPP.

Table II. Analysis of the Thermal Decomposing Properties for the Chicken-Feather Protein-Based P–N Flame Retardant

Decomposition stages	Initial–final decomposition temperature (°C)	Weight retention rate (%) after each stage
1	115.11-164.93	90.39
2	254.97-319.16	77.66
3	416.71-474.95	68.39
4	894.93-987.42	45.15

Flame Retardancy of the Cotton Fabric Treated with Different Flame Retardants

The flammability behaviors of untreated cotton fabric (control) and the treated cotton fabrics with the chicken-feather protein-based flame retardant alone and with borax and boric acid alone and with the combination of them (the constituents of the flame-retardant finishing bath can be seen in Table I) were tested according to the Chinese standard of GBIT5455-1997 test of "The flammability test of textiles with the vertical burning experiment" and the Chinese standard of GB/T5454-1997 test of "The flammability test of textiles with the oxygen index method," respectively. The experimental results are represented in Table III. It could be found from Table III that the oxygen indexes of all treated cotton fabrics increase obviously in comparison with the untreated cotton fabric. And the treated cotton fabrics with the chicken-feather protein-based flame retardant alone and with borax and boric acid alone burn out due to the weight gain rate of the flame retardant on the cotton is not enough (very low) to obtain the flame retardancy. But the flame retardancy of the combination of the chicken-feather protein-based flame retardant and borax and boric acid is the best (the char length and the after flame and the after glow were the lowest, and the oxygen index was the highest) among the three samples. It was found that the combined flame-retardant finished cotton fabric showed good flame retardancy at weight gain rate of 8.10%, and it was further observed that the formed

Table III. Flame Retardancy of Untreated and Treated Cotton Fabrics by Different Flame Retardants

Sample	Weight gain rate (%)	Char length (cm)	After glow (s)	After flame (s)	LOI
1#	5.72	>30	180	7	30.1
2#	2.77	>30	1	29	29.5
3#	8.10	4.5	2	0	39.9
4#	0	>30	10	12	18.0

1#: the chicken-feather protein-based flame retardant; 2#: borax and boric acid; 3#: the combination of them; 4#: the unfinished cotton fabric.

Table IV. Flame Retardancy of the Finished Cotton with Different Concentrations of the Chicken-Feather Protein-Based Flame Retardant and Combined with Borax and Boric Acid

The concentrations of the P–N flame retardant (g/L)	Weight gain rate (%)	Char length (cm)	After glow (s)	After flame (s)
0	2.77	>30	1	29
50	4.20	>30	9	16
100	5.57	6.0	1	0
150	6.40	5.0	1	0
200	7.40	4.5	1	0
250	8.10	4.5	2	0

*10 g/L of borax and 60 g/L of boric acid were add in all finishing bath.

residual char of the combined flame-retardant finished cotton fabric after burning still maintained the weaved structure and left behind a lot of ash, indicating that the combined-finished cotton fabric attains high thermal stability and excellent char-forming ability. Therefore, it was concluded that a combination of the chicken-feather protein-based flame retardant and borax and boric acid had a good synergistic effect on enhancement of flame retarding performance of the finished cotton fabric. Whereas when the untreated cotton was subjected to flame, it burnt immediately leaving behind a small amount of ash.

In order to investigate synergistic effect of a combination of the chicken-feather protein-based flame retardant and borax and boric acid, we studied the flame retardancy of the finished cotton with different concentrations of the chicken-feather protein-based flame retardant and combined with borax and boric acid and the results are shown in Table IV. It could be found from Table IV that the char length decreases with the increase of the concentrations of the chicken-feather protein-based flame retardant and with the increase of the weight gain rate of the flame retardant attached on the cotton fabric. When the concentrations of the chicken-feather protein-based flame retardant is above 100 g/L, the weight gain rate of the flame retardant attached on the cotton fabric is over 5.57%, the finished cotton fabric shows good flame retardancy, the flame ignited on the flame-retardant–treated fabric is extinguished right after removal of the ignition source, leaving fabric with only a spot of char formation. When the concentrations of the chicken-feather protein-based flame retardant is 200 g/L, the char length

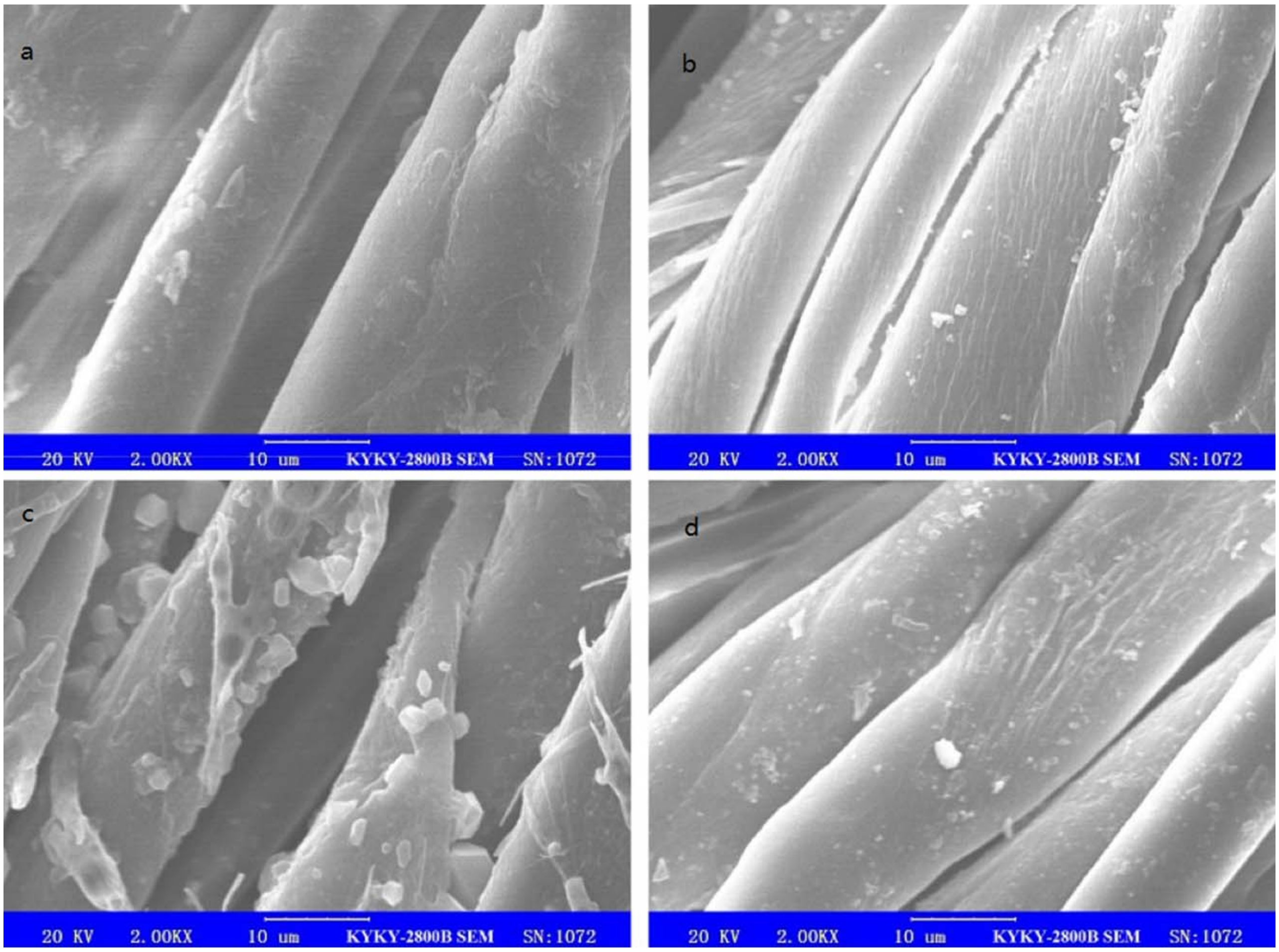


Figure 3. SEM photographs of the finished cotton fabrics with borax and boric acid (a) and with the chicken-feather protein-based flame retardant (b) and with combined-finished cotton fabric (c) and the SEM photographs of the unfinished cotton fabric (d). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

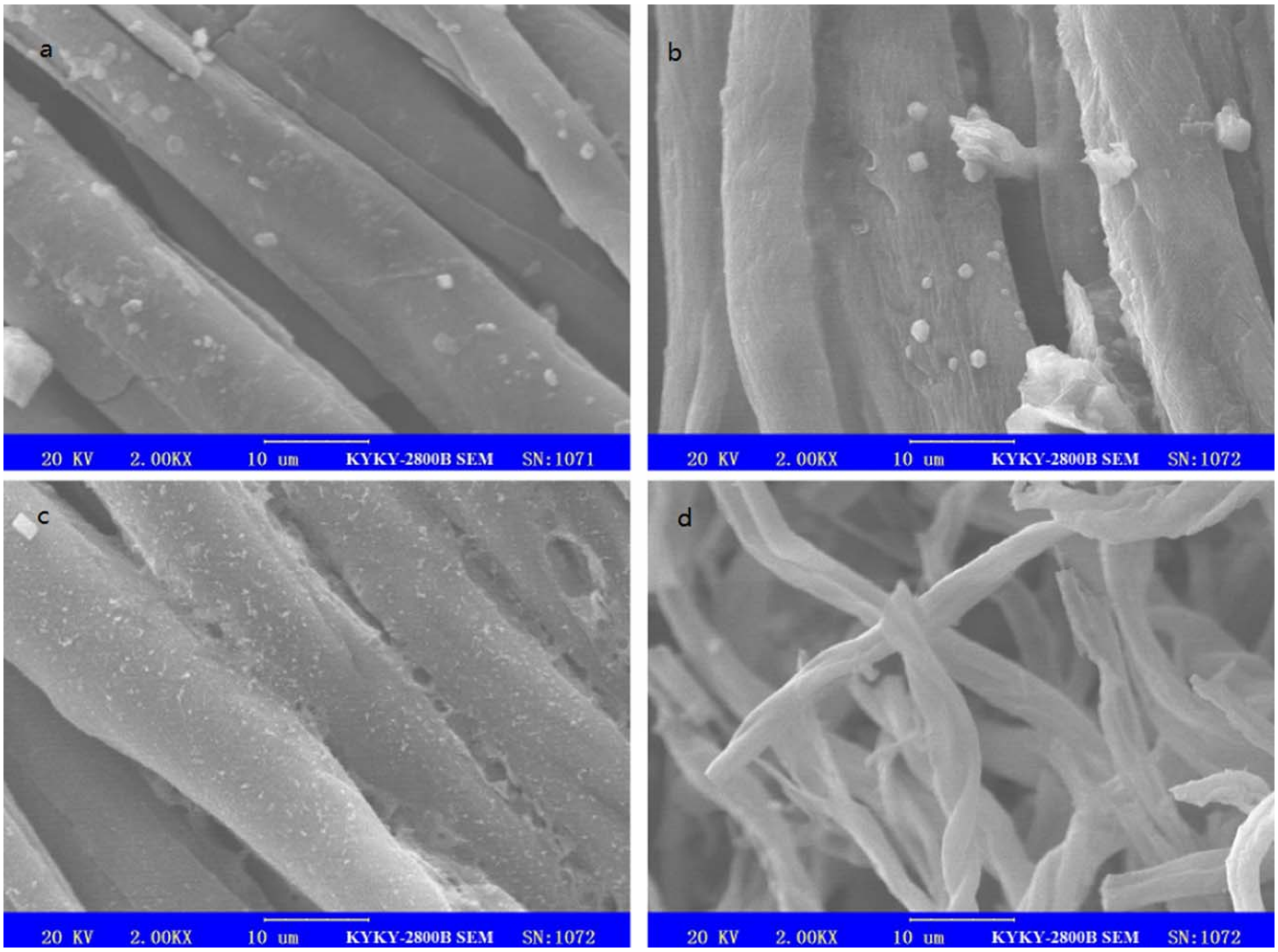


Figure 4. SEM photographs of the residual char layer of borax and boric acid finished cotton fabric (a) and the chicken-feather protein-based flame retardant finished cotton fabric (b) and combined-finished cotton fabric (c), and unfinished cotton fabric (d). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

reaches the lowest. But when the concentrations of the chicken-feather protein-based flame retardant is 250 g/L alone (see Table III), the weight gain rate reaches at 5.72%, and the finished cotton fabric is burn out. And it could also be seen that the treated fabric with borax and boric acid alone is also burn out. However, when borax and boric acid were added in the chicken-feather protein-based flame retardant finishing bath, good flame retardance was obtained. So it indicated that the combination of the chicken-feather protein-based flame retardant and borax and boric acid has a good synergistic effect on enhancement of flame retarding performance of the finished cotton fabric.

The Changes in Surface Morphological Structures of the Unburned Cotton and Burned Residual Char Layer of Unfinished and Finished Fabrics by Different Flame Retardants

The morphologies of the untreated cotton fabric and the treated cotton fabric with the chicken-feather protein-based flame retardant alone, with borax and boric acid alone and with the combination of them were observed by SEM, as shown in Figure 3.

From Figure 3, it could be seen clearly that the surface morphological structure of the untreated fiber is smooth and, apart from the slight cracking on the fiber surface, no significant surface structural features can be observed [Figure 3(d)]. On the other hand, the presence of the coating could be easily observed on the surface morphology of the treated cotton fabric by the feather-protein based flame retardant agent alone and by borax and boric acid alone, and by combination of them. When compared with Figure 3(a, b, d), Figure 3(c) clearly showed that the flame retardants were unevenly distributed on the fiber surface, and agglomeration of particles was observed due to the attraction between the agents. Moreover, the surface of the combined-treated cotton fabric exhibited much more irregular-shaped agents' particles, that is, it confirmed much more flame retardants deposits on the surface of the treated cotton. It illustrates that the combination of the chicken-feather protein-based flame retardant and borax and boric acid has a synergistic effect to facilitate the deposition of finishing agent on the fiber surface.

Figure 4 showed the SEM photographs of the surface of the residual char formed after combustion of the untreated cotton fabric and the treated cotton fabric by chicken-feather protein-based flame retardant alone and by borax and boric acid alone and by the combination of them, respectively. From Figure 4(d), it could

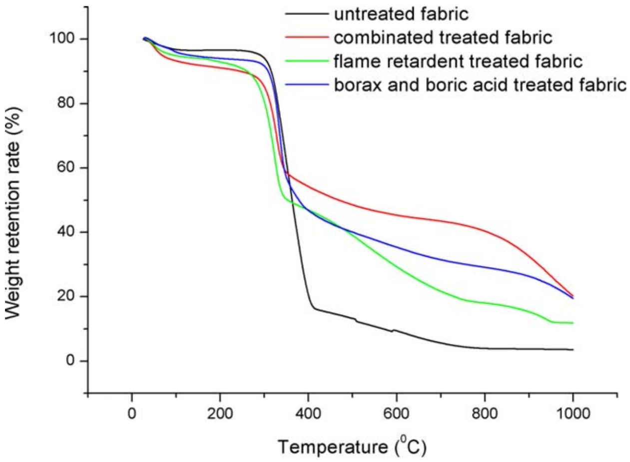


Figure 5. TGA curves of untreated and treated cotton fabrics by different flame retardants. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

be observed that the residual char of the untreated cotton fabric was very loose and porous, so it cannot provide good flame shield, leading to poor flame retardancy of the untreated fabric. From Figure 4(a–c), it was found that the charred crust of the treated cotton fabrics were more compact and thicker than that of the untreated cotton fabric. Compared with Figure 4(a, b), the surface of the residual char layer of borax and boric acid finished cotton fabric was smooth and thin, not formed an efficient intumescent char layer. But the thicker intumescing char layer was formed for the chicken-feather protein-based flame retardant finished cotton fabric, indicating the intumescent flame retardant mechanism of the chicken-feather protein-based flame retardant. It could also be seen that the residual char layer of the combined-finished cotton fabric was the densest and most compact intumescent char layer among all of the samples. The higher and more compact char is beneficial to prevent the heat and mass transfer between the flame zone and the burning substrate, thus protecting the underlying materials from further burning. So it indicated that the combination of the chicken-feather protein-based flame retardant and borax and boric acid could promote to form a homogenous and compact intumescent char layer, so the combination of them has a good synergistic effect in the improving flame retardancy.

TGA of the Cotton Treated by Different Flame Retardants

Figure 5 showed the TGA curves of the untreated cotton fabric and the treated cotton fabrics by chicken-feather protein-based flame retardant alone and by borax and boric acid alone and by the combination of them, respectively. And the thermal data are represented in Table V. It could be found from Figure 5 that the thermal decomposing behaviors of the flame retardant finished cotton fabrics are much different from that of untreated cotton. The biggest decomposition rate of untreated cotton occurs in the ranges of 305.85°C–386.52°C, and the percentage of weight loss in the temperature range is 80.67%. Whereas the biggest decomposition rate of the treated cotton by chicken-feather protein-based flame retardant, borax and boric acid, and the combination of them occurs in the ranges of 289.60°C–328.20°C, 310.55°C–340.83°C, and 297.45°C–330.81°C, respectively, and the percentage of weight loss in the temperature range is 41.73%, 50.10%, and 34.49%, respectively. In comparison with the untreated fabric, it illustrated that the treated cotton alters its burning process. It was clearly seen that the initial biggest decomposing temperature of the untreated cotton is higher than that of the treated cotton by chicken-feather protein-based flame retardant and lower than that of the treated cotton by borax and boric acid. And the initial biggest decomposing temperature of the treated cotton by the combination of them is higher than that of the treated cotton by chicken-feather protein-based flame retardant and lower than that of the treated cotton by borax and boric acid. It could also be observed that the percentage of weight loss in the temperature ranges of the biggest decomposing rate of the untreated cotton is the biggest among the four samples, and the percentage of weight loss in the temperature ranges of the biggest decomposing rate of the treated cotton by the combination of chicken-feather protein-based flame retardant and borax and boric acid is the lowest among the four samples. Moreover, untreated cotton after decomposition at the same temperature (above 400°C) left the least residual weight (e.g., left about 3.74% of char residue at 900°C), having the poor carbonation. About 15.30%, 26.32%, and 32.55% solid residue are left for the treated fabrics by chicken-feather protein-based flame retardant alone and by borax and boric acid alone and by the combination of them after decomposition at 900°C, respectively. It showed that the percent of the residue left of the treated cotton is much higher than that of untreated cotton after burnt. The reason for the improvement of the thermal behavior and the flame retardancy of the treated cotton may be explained by the fact that increasing carbonation and forming a protective layer on cotton fabric, which will inhibit the transferring of heat and mass between the flame zone and

Table V. The Thermal Decomposition Properties of Untreated and Treated Cotton Fabrics by Different Flame Retardants

Fabric	The temperature range of the biggest decomposition rate (°C)	Weight retention rate (%) at different temperatures (°C)						
		300	400	500	600	700	800	900
1#	289.60-328.20	80.62	46.96	39.09	29.32	21.70	18.03	15.30
2#	310.55-340.83	91.69	46.80	40.05	35.37	31.49	29.12	26.32
3#	297.45-330.81	85.22	54.23	48.53	45.33	43.48	40.35	32.55
4#	305.85-386.52	94.12	20.48	13.25	9.41	5.60	3.92	3.74

1#: the chicken-feather protein-based flame retardant; 2#: borax and boric acid; 3#: the combination of them; 4#: the unfinished cotton fabric.

the burning substrate, and will inhibit the spreading of the flame, thus protecting the underlying materials from further burning, and comprises a complete intumescent system resulting in the decrease of flammability. From the experimental results, it was found that the char yield of the treated cotton with combination of chicken-feather protein-based flame retardant and borax and boric acid increase greatly and much denser char residue form, so it illustrated the importance of borax and boric acid addition in the finishing bath, which indicated that the thermal degradation reaction of the combined-treated cotton changes, thereby the flame retardant performance of the combined-treated cotton fabric improves more obviously. So combination of chicken-feather protein-based P–N flame retardant and borax and boric acid has a good synergistic effect on charring.

CONCLUSIONS

A novel chicken-feather protein-based P–N flame retardant was synthesized. The agent has high thermal stability and excellent char-forming ability, which is much higher than that of MPP. The flame-retardant–treated cotton fabric has a lower initial biggest decomposing temperature and produces much higher char yields at high temperature in nitrogen and obtains much higher LOI in comparison with untreated cotton. The thermal behavior and flame retardancy of the cotton fabric treated by the chicken-feather protein-based P–N flame retardant in combination with borax and boric acid were enhanced further, and the combined-treated cotton fabric could promote to form a homogenous and compact intumescent char layer. The results evidenced that the flame retardancy and thermal stability and char-forming ability of the combined-treated cotton fabric improved highly, and the results proved that combination of the chicken-feather protein-based flame retardant and borax and boric acid has good synergistic effect on improvement of flame retarding performance of the finished cotton fabric.

REFERENCES

1. Lam, Y. L.; Kan, C. W.; Yuen, C. W. M. *Cellulose* **2011**, *18*, 151.
2. Yoshioka-Tarver, M.; Condon, B. D.; Easson, M. W.; Nam, S.; Fortier, C. A.; Madison, C. A.; Ingber, B. F. *AATCC Rev.* **2012**, *9*, 52.
3. Easson, M.; Condon, B.; Yoshioka-Tarver, M.; Childress, S.; Slopek, R.; Bland, J.; Nguyen, T.; Chang, S.; Graves, E. *AATCC Rev.* **2011**, *11*, 60.
4. Nguyen, T. D.; Chang, S.; Condon, B.; Uchimiya, M.; Fortier, C. *Polym. Adv. Technol.* **2012**, *23*, 1555.
5. Zhao, X. *J. Text. Inst.* **2010**, *101*, 538.
6. Nguyen, T. D.; Chang, S.; Condon, B.; Uchimiya, M.; Graves, E.; Smith, J.; Easson, M.; Wakelyn, P. *Polym. Adv. Technol.* **2012**, *23*, 1036.
7. Verma, S. K.; Kaur, I. *J. Appl. Polym. Sci.* **2012**, *125*, 1506.
8. Totolin, V.; Sarmadi, M.; Manolache, S. O.; Denes, F. S. *J. Appl. Polym. Sci.* **2012**, *124*, 116.
9. Deo, H. T.; Patel, N. K.; Patel, B. K. *J. Eng. Fiber. Fabr.* **2008**, *3*, 23.
10. El-Tahlawy, K. *J. Text. Inst.* **2008**, *99*, 185.
11. Lipkowski, A. W.; Gajkowska, B.; Grabowska, A.; Kurzepa, K. *Polimery* **2009**, *54*, 386.
12. Lin, H.; Sritham, E.; Lim, S.; Cui, Y.; Gunasekaran, S. *J. Appl. Polym. Sci.* **2010**, *116*, 602.
13. Wang, X.; Peng, Y. *J. Appl. Polym. Sci.* **2011**, *119*, 1627.
14. Martelli, S. M.; Laurindo, J. B. *Int. J. Polym. Mater.* **2012**, *61*, 17.
15. Bosco, F.; Carletto, R. A.; Alongi, J.; Marmo, L.; Di Blasio, A.; Giulio, M. *Carbohydrate Polym.* **2013**, 372.
16. Saravanan, K.; Dhurai, B. *JTATM* **2012**, *7*, 1.
17. Fang, K.; Li, J.; Ke, C.; Zhu, Q.; Zhu, J.; Yan, Q. *Polym. Plast. Technol. Eng.* **2010**, *49*, 1489.
18. Zhang, F.; Zhang, J.; Jiao, C. M. *Polym. Plast. Technol. Eng.* **2008**, *47*, 1179.