Energy and Water Saving Finishing Method for Producing Durable Flame Retardant Cotton Fabric

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Abstract

This study presents the improvement of durable flame retardant (FR) effect of 100 % cotton fabrics via chemical foaming system which provides energy and water saving significantly, compared to conventional methods. In order to carry out the experiments, dialkylphosphonocarboxylic acid amide based flame retardant agent and auxiliary chemicals were applied on cotton fabrics in a foam formed. Foam parameters such as blow ratios and wet-pick-up ratios were varied and flame retardant properties of foamed cotton fabrics were compared with cotton fabrics treated through pad-dry-cure process in order to determine the performance effect of cotton fabrics in flame retardancy via different finishing methods. After the finishing processes, flame retardant effect of all treated fabrics was examined with vertical burning test method. As durability of flame retardant applied cotton fabrics against washing process is one of the most important subjects that has been tried to be improved with different approaches for a long time, all treated fabrics were washed and dried 50 times, separately. After repeated washing and drying cycles, burning behavior of washed and FR treated fabrics were also tested vertically for determining flame retardancy effect. Beside the vertical burning test, tearing strength test, color spectrums, SEM and SEM-EDX analysis of fabrics were carried out. According to test results, even at the low wet-pick-up ratios, a significant increase was observed in flame retardant effect of cotton fabrics that were treated with FR agents via foam application. Moreover, all treated fabrics were durable against 50 washing and 50 drying processes.

Keywords: Chemical foam system, cotton fabric, flame retardancy, durable effect, water-saving

I. INTRODUCTION

Fires occurred from upholstered furniture, floor coverings, curtains, drapes or clothing worn by people can result in high rate of fatalities or serious burns in their bodies [1-6] that’s why researches have been carried out for years in order to improve flame retardant effects of cellulosic based materials which have high flammability [3, 7-9]. There are several studies performed with conventional methods on flame retardant finishes, however one of the biggest issue of conventional methods is high amount of water and energy consumption during the finishing processes. In order to save water and energy which is one of the most important subjects nowadays that has been studying on for our world’s sustainability, some other new technologies have been improved. Beside conventional methods, there are some alternative finishing application methods that allow low pick-up ratios as foaming technology. The use of air to extend the volume of a chemical solution in the form of bubbles showed in Fig. 1 is
known as a foaming process. Foaming liquor to a large volume allows volumetric control and hence ensures even distribution of the liquor on the fabric. Foaming technology has offered solutions to the basic problems encountered with the other low-add-on topical and expression systems [3, 10]. Thus, in this study, FR agents were applied to 100% cotton fabrics and flame retardant effect of cotton fabrics which were performed through both conventional finishing and chemical foaming system were examined.

![Fig.1. Structure of foam bubble used in textile industry [11]](image)

II. EXPERIMENTAL

A. Material-Method

400 g/L Dialkylphosphonocarboxylic acid amide based chemical as FR agent, 12 g/L phosphoric acid, 25 g/L emulsion of polyalkylene and 55 g/L melamine formaldehyde as auxiliary chemicals (Huntsman, USA) applied on twill 100% cotton fabrics (Cotton Incorp., Cary, USA) with both chemical foam system and padding application. Foam parameters as wet pick-up ratios were varied in order to determine and optimize the flame retardant effect of the fabrics. Wet pick-up ratio was 60% in padding system whereas two different wet-pick up ratios were performed as 35% and 30% in foaming system, respectively. As a foaming device, Gaston Systems Chemical Foaming System (CFS, Gaston, USA) was used as showed in Fig. 2, and the test results were compared with conventional padding system. After the required applications, according to AATCC Test Method 193-2007, repeated washing cycles were performed and after each washing cycle, 45 min drying procedure were carried out up to 50 times. After every 5 or 10 washing and drying cycles, each performance tests such as vertical burning test (ASTM D6413/D6413M-12), color spectrums (Spectraflash SF 600X Datacolor Reflectance Spectrophotometer) and tearing strength tests (ASTM D1424) were also carried out. As characterization tests, SEM and SEM-EDX (Hitachi S-3200N) analysis were performed. Codes of treated cotton fabrics were written as following:

PFR: Cotton fabric padded with flame retardant agent CPF1: Cotton fabric foamed with flame retardant agent with a liquor-ratio of 35%  
CPF2: Cotton fabric foamed with flame retardant agent with a liquor-ratio of 30%  
5W: 5 times washed and 5 times dried sample  
10W: 10 times washed and 10 times dried sample  
20W: 20 times washed and 20 times dried sample  
30W: 30 times washed and 30 times dried sample  
40W: 40 times washed and 40 times dried sample  
50W: 50 times washed and 50 times dried sample
III. DISCUSSION AND RESULTS

A. Vertical Burning Test Results

Vertical burning test results showed that untreated cotton fabric was burned totally and flame retardant effect of all treated cotton fabric was improved including padding system showed in Fig. 3, however; in foam application system there was a significant increase in flame retardancy effect even at low wet-pick up ratios as showed in Fig. 4 and Fig. 5.

-- Chart 3: Char lengths (cm) of PFR and washed-dried versions of it up to 50 cycle after vertical burning test

-- Chart 4: Char lengths (cm) of CPF1 and washed-dried versions of it up to 50 cycle after vertical burning test
B. Tearing Strength Test Results

Tearing test results showed that there was a decrease in all FR treated fabrics but this decrease was more significant in PFR sample as it was seen in Table 1. It was considered that this decrease was observed because of melamin-formaldehyde used in FR recipe of this study which prevented the movement of the fibers of the cotton fabric when tearing force was applied.

| Fabric | Warp Direction | Weft Direction |
|--------|----------------|----------------|
| PFR    | 25             | 26             |
| CPF1   | 34             | 28             |
| CPF2   | 35             | 29             |

C. Color Spectrum Test Results

Color spectrum values, yellowness indexes and ΔE values of PFR, CPF1 and CPF2 were showed, respectively in Table 2, Table 3 and Table 4. There was a significant change in ΔE values of washed and dried versions of PFR samples whereas this change was less in the washed-dried versions of foamed cotton fabrics. When color spectrums of all treated unwashed fabrics (PFR, CPF1, CPF2) were examined, it could be clearly seen that the ΔE values were close to each other. In all samples, yellowness indexes decreased when the number of repeated washing-drying cycles was increased.
Table 2. Color spectrums, yellowness indexes (YI) and ΔE values of PFR

| Sample | L⁺ | a⁺ | b⁺ | YI-1925D | ΔE  |
|--------|----|----|----|----------|-----|
| PFR    | 59.55 | 3.04 | 14.38 | 40.00 | 1.35 |
| 5WPFR  | 60.68 | 3.02 | 13.76 | 38.06 | 2.49 |
| 10WPFR | 61.09 | 2.97 | 13.54 | 37.34 | 2.94 |
| 20WPFR | 61.62 | 2.94 | 13.20 | 36.29 | 3.56 |
| 30WPFR | 61.88 | 2.73 | 13.27 | 36.11 | 3.78 |
| 40WPFR | 61.99 | 2.80 | 13.11 | 35.67 | 3.94 |
| 50WPFR | 62.80 | 2.83 | 12.87 | 34.95 | 4.72 |

Table 3. Color spectrums, yellowness indexes (YI) and ΔE values of CPF1

| Sample | L⁺ | a⁺ | b⁺ | YI-1925D | ΔE  |
|--------|----|----|----|----------|-----|
| CPF1   | 57.43 | 3.14 | 15.32 | 43.30 | 1.53 |
| 5WCPIF1| 58.01 | 3.02 | 14.60 | 41.24 | 1.29 |
| 10WCPIF1 | 58.18 | 3.13 | 14.62 | 41.30 | 1.11 |
| 20WCPIF1 | 59.19 | 3.00 | 14.10 | 39.51 | 1.43 |
| 30WCPIF1 | 59.77 | 2.92 | 13.37 | 38.61 | 1.88 |
| 40WCPIF1 | 59.85 | 2.92 | 13.66 | 38.09 | 2.07 |
| 50WCPIF1 | 60.35 | 2.87 | 13.73 | 37.98 | 2.33 |
Table 4. Color spectrums, yellowness indexes (YI) and ΔE values of CPF2

| Samples | L*   | a*   | b*   | YI-1925D | ΔE  |
|---------|------|------|------|----------|-----|
| CPF2    | 57.18| 3.27 | 15.52| 44.04    | 1.75|
| 5WCFS2  | 58.00| 3.09 | 14.72| 41.58    | 1.20|
| 10WCFS2 | 57.97| 3.16 | 14.61| 41.43    | 1.23|
| 20WCFS2 | 58.53| 3.13 | 14.57| 41.33    | 0.99|
| 30WCFS2 | 59.34| 3.00 | 13.99| 39.18    | 1.56|
| 40WCFS2 | 59.56| 3.03 | 13.97| 39.08    | 1.63|
| 50WCFS2 | 60.11| 2.96 | 13.77| 38.29    | 2.12|

D. SEM Results

SEM micrographs at x2000 magnification were seen in Fig. 6 which indicates untreated, PFR and CPF1 samples, respectively. The surface of untreated sample was smooth and clean while there were residues of chemical on the padded cotton fabric. Chemicals applied via foaming system were seen as small black particles on foamed cotton fabric in Fig. 6c.

![SEM micrographs of a) Untreated sample b) PFR c) CPF1](image_url)
E. SEM-EDX Test Results

SEM-EDX test result showed clearly in Fig. 7 that phosphorus based flame retardant chemical applied on cotton fabric via foaming system with the sharp peak of phosphor (P).

Fig. 7. SEM-EDX analysis of CPF1

IV. CONCLUSION

As a conclusion, a significant improvement on flame retardant effect of cotton fabrics was achieved via chemical foam application. It was observed that improved flame retardant effects could be performed on 100 % cotton fabrics with low wet-pick up ratios. Even though there was a decrease in tearing strength test results after each FR finishing applications, in chemical foaming system these decreases were less than the conventional finishing treatment. According to test results, even at the low wet- pick-up ratios, a significant increase was observed in flame retardant effect of cotton fabrics that were treated with FR agents via foam application. Moreover, all treated fabrics were durable against 50 washing and 50 drying processes.

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