FR Performance of New Fire-off on PET/CO blend fabrics

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Abstract. This paper represents the investigation on flame retardancy performance and durability of polyester /cotton (P/C) fabrics treated with a novel halogen/formaldehyde free, P-N synergetic FR finishing agent called New Fire-off. 100 % Cotton, 100 % Polyester and three different blend P/C fabrics were chosen in this study. Fabric samples were treated with New Fire-off through pad-dry-cure process. Flammability and thermal properties of the treated samples with New Fire-off were tested according to relevant ISO standard and procedures. The obtained results showed that this new finishing formulation is a good char-forming agent. However, further studies are required to achieve washing durability for the P/C blends.

1. Introduction
The natural and synthetic fibre blends are so popular than using pure fibre alone, as a consequence of combining good properties of blended each fibres. Polyester/Cotton (P/C) blends are widely used in home textiles, clothing and knitwear due to their high strength, excellent wearing resistance, good hygroscopicity, and high air permeability properties [1]. Fire retardancy is one of the essential properties for these blends. Polyester fibre (thermoplastic) shrinks at its melting point and run away from the fire while cotton fibre becomes char form. If a blend of these cotton and polyester is burned, the molten polyester generally tends to wick on cotton char and this result the ‘scaffolding effect’ [2].

Halogenated flame retardant systems are popular and widely used in FR coating and finishing formulations. However their use is being restricted due to environmental problems [3]. Similarly, the phosphorus-nitrogen (P-N) FR systems, Fyrol 76, Fyroltex HP, Pyrovatex CP New, and Proban shows a good N-P synergism for P/C, but these methods have a formaldehyde-released problem [4-8]. Over the past years, there has been an increasing trend in the flame retardance community to develop flame retardant coating systems or finishes for textiles with a major focus on phosphorus based, halogen and/or formaldehyde-free systems [3, 9].

In our previous work, a novel halogen-and formaldehyde free, P-N synergetic FR finishing agent called Fire-off (PVA (PR)-P-DCDA) had been synthesized by polyvinyl alcohol (PVA), hydrophilic polyester resin (PR), phosphoric acid and dicyandiamide (DCDA). Then, Fire-off was applied to 100% cotton, 100% polyester and 50/50% P/C fabrics via pad-dry-thermosol process. A durable flame retardancy (FR) achieved with Fire-off for 100% Polyester fabrics up to 20 domestic laundering cycles. However P/C fabrics were not durable against washing. In order to improve FR efficiency and washing durability of P/C fabrics, the amount of P % content of the polymer was increased and obtained chemical was called New Fire-off.
In this study, FR performance of New Fire-off on P/C fabrics with different blend ratios was investigated and assessed in terms of the durability against home laundering.

2. Experimental

2.1. Materials

The fabrics used were cotton, polyester and C/P blends (Table 1) supplied from BJ Textile, Erdem Textile and Zorlu Textile companies.

As a FR chemical, PVA (PR)-P-DCDA with 1.83% of increase in P content (New Fire-off) was prepared in Eksoy Chemical Company.

| No | Fabric Type       | Fabric Density |
|----|------------------|----------------|
| 1  | 100% P knitted   | 132 g/m²       |
| 2  | 60/40% P/C knitted | 392 g/m²     |
| 3  | 30/70% P/C knitted | 365 g/m²     |
| 4  | 50/50 % P/C woven | 185 g/m²     |
| 5  | 100% C woven     | 112 g/m²       |

2.2. Fabric Treatment and Home Laundering Procedures

All fabric samples were firstly immersed in 400 g/L New Fire-off bath at room temperature to give ~100% pick-up regulated by padding. After two-dips and two-nips, they were dried at 100°C for 3 min, and then cured at 180°C for 3 min. The calculated add-on of FR was between 25-40%.

After curing, the treated fabrics were subjected to a different number of laundering/drying cycles according to ISO 6330/4G Test Method -2012 Textiles - Domestic washing and drying procedures for textile testing for durability assessment.

2.3. Flammability and Thermal Properties Evaluation of the Treated Fabrics

The vertical burning test (Figure 1) including flame application time, ignition time, and char length/width was conducted according to ISO 6940:2006 entitled "Textile fabrics - Burning behaviour - Determination of ease of ignition of vertically oriented specimens to evaluate FR properties of the finished fabrics. Also, LOI test was carried out according to BS 4589-2.

![Figure 1. Vertical Flammability Test](image)
20x5 cm lengthwise specimens were prepared and left for 24 hours condition. The conditioned specimens were then mounted in a suitable clamp and placed in a standard cabinet that allows 2 mm/second airflow, and the bottom edge of the fabric was exposed to a standard flame for 1 second to its ignition time under controlled conditions. Treated fabrics were subjected to flame for only 20 seconds.

Thermal properties of treated fabrics were also investigated through thermal gravimetric analysis (TGA) and differential thermal analysis (DTA).

3. Results and Discussion

3.1. Vertical Flammability Test and LOI Results

All treated fabrics passed the vertical flammability test. After 20 s of flame exposure to the specimens, they were not ignited and did not show after-glow. Test results are exhibited on Table 2, including char length/width and mass loss %.

| No | Fabric Type          | Fabric Density | Time to flame subjection | Mass loss % | Char length/width |
|----|----------------------|----------------|--------------------------|-------------|-------------------|
| 1  | 100% P knitted       | 132 g/m²       | 20 s                     | 6,96        | 8,3 / 2,3 cm      |
| 2  | 60/40% P/C knitted   | 392 g/m²       | 20 s                     | 2,78        | 8,7 / 1,9 cm      |
| 3  | 30/70% P/C knitted   | 365 g/m²       | 20 s                     | 3,63        | 9 / 2,1 cm        |
| 4  | 50/50 % P/C woven    | 185 g/m²       | 20 s                     | 4,98        | 10 / 1,9 cm       |
| 5  | 100% C woven         | 112 g/m²       | 20 s                     | 10,34       | 11,8 / 2,5 cm     |

As seen from the table, 100 % cotton fabric has the highest value in mass loss % and char length/width value among other fabric samples while 60/40% P/C fabric has lowest values. If FR performance of P/C fabrics were compared, 60/40% P/C has better values in terms of mass loss and char length. It is well known that fabrics density is strongly related to FR performance. 60/40% P/C has also an advantage of heavier weight as well as higher polyester ratio. By comparing 100 % cotton and 100 % polyester, it is obviously seen that New Fire-off treatment have better FR results in polyester fabrics than cotton fabrics. Therefore, it could be said that there is also a direct relation between FR performance and polyester ratio of treated fabrics.

Flammability of the fabrics after laundering cycles of 5, 10, 15 and 20 were also evaluated in term of FR properties against washing. The results are listed on Table 3. It was observed that 100 % cotton fabric burns rapidly while C/P blends extinguish themselves and burn very slowly. As it is seen from the table that ignition times almost did not changed after 5 washing cycles. So, fabrics lost most of their FR performance in 1-5 cycles.

| No | Fabric Type          | Fabric Density | Ignition time after 5 washing cycles | Ignition time after 10 washing cycles | Ignition time after 15 washing cycles | Ignition time after 20 washing cycles |
|----|----------------------|----------------|-------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| 1  | 100% P knitted       | 132 g/m²       | 10                                  | 10                                   | 9                                    | 9                                    |
| 2  | 60/40% P/C knitted   | 392 g/m²       | 13                                  | 13                                   | 13                                   | 13                                   |
| 3  | 30/70% P/C knitted   | 365 g/m²       | 14                                  | 14                                   | 14                                   | 14                                   |
| 4  | 50/50 % P/C woven    | 185 g/m²       | 11                                  | 11                                   | 11                                   | 11                                   |
| 5  | 100% C woven         | 112 g/m²       | 10                                  | 10                                   | 9                                    | 9                                    |
LOI values of treated and untreated fabrics are given in Table 4. FR treatments with Fire-off on polyester and P/C blends lead an increase in LOI values from 18-19 to 26-27.

### Table 4. LOI test results of untreated and treated C/P fabrics.

| No | Fabric Type       | Fabric Density | LOI of untreated fabric | LOI of treated fabric | LOI after 5 wash |
|----|-------------------|----------------|-------------------------|-----------------------|-----------------|
| 1  | 100% P knitted    | 132 g/m²       | 19-20                   | 26.5-27               | ND              |
| 2  | 60/40% P/C knitted | 392 g/m²     | 19                      | 26.5-27               | 21              |
| 3  | 30/70% P/C knitted | 365 g/m²     | 19                      | 26.5-27               | 21              |
| 4  | 50/50% P/C woven  | 185 g/m²      | 18-19                   | 25.5-26               | 20-21           |
| 5  | 100% C woven      | 112 g/m²      | ND                      | ND                    | ND              |

*ND: Not detected

3.2. **Thermogravimetric and Differential Thermal Analysis of Treated Fabrics**

Thermal changes of treated P/C fabrics are shown in Figure 2, and collected numerical datas are given in Table 5.

a) 100% P knitted

![Thermogravimetric and Differential Thermal Analysis of Treated Fabrics a) 100% P knitted](image)

b) 60/40% P/C knitted

![Thermogravimetric and Differential Thermal Analysis of Treated Fabrics b) 60/40% P/C knitted](image)
c) 30/70% P/C knitted

d) 50/50% P/C woven

e) 100% C woven

Figure 2. TGA/DTA of treated fabrics with New Fire-off.
Table 5. Collected datas from TGA/DTA graphs of treated fabrics

| No | Fabric Type   | T_d 0.05 / T_d 0.5 (°C) | T_g / T_m (°C) | ΔH_m (uV.s/mg) |
|----|---------------|-------------------------|----------------|---------------|
| 1  | 100% Polyester| 55.8 / 296              | 70.7 / 267.3   | 6.45          |
| 2  | 60/40% P/C    | 109.2 / 394.8           | 66.9 / 246.3   | 10.61         |
| 3  | 30/70% P/C    | 67.1 / 368.9            | 68.2 / 286.5   | 14.93         |
| 4  | 50/50% P/C    | 82.1 / 399.1            | 65.6 / 246.2   | 7.13          |
| 5  | 100% Cotton   | 68.8 / 304.9            | 64.3 / 306     | -33.00        |

It is clearly seen from the Table 5 that T_m and ΔH_m values of 30/70% P/C fabrics are highest among the other fabrics, which can be attributed to high flame retardancy with increased char formation. Although 60/40% P/C and 50/50% P/C have very similar T_g / T_m and T_d 0.5 (°C) values, ΔH_m value of 60/40% P/C is higher than 50/50% P/C. It indicated that 60/40% P/C fabric has better flame retardancy than 50/50% P/C.

4. Conclusion and Directions for Further Study
In this study, FR properties and durability performance of 100% C, 100% P and P/C fabrics treated with New Fire-off were investigated. Results showed that FR were successfully rendered the all fabrics with New Fire-off. As fabrics consisted of higher ratio polyester demonstrated better FR properties, New Fire-off is more effective on the polyester part of the blends. However, all fabrics lost most of their FR properties between 1-5 home washing. So, durability against washing still needs to be improved for all the fabrics.

Further studies could focus on modifications of the synthesis of Fire-off and using cross linkers for the cotton part of the blends to increase FR properties and durability.

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