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Fire Retardant Finishing of Cotton Fabrics

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Abstract- The cellulosic nature of cotton fibre makes it flammable material and it is one of the key reasons behind excessive fire accidents within the textile industry. The importance of fire retardant finishes can't ignore which significantly enhance the resistance to flammability of cotton fabrics. Cross linkers used as a binder for fire retardant finishes to fix them with textile material in order to make it long-lasting. The addition of cross-linkers enhanced the utilization of fire retardant finishes exclusively upon kids' wear. The softeners play a pivot role to reduce the stiffness produced by the utilization of cross linkers and finishes. In this research work eco-friendly cross-linker was used to enhance the stability of fire retardant finishes upon cotton fabric. The study showed an enhancement in the fire retardant properties by increasing the proportion of flame retardant in addition to the proportion of phosphoric acid. When cross-linker was added to the finish solution, the results indicate that the addition of cross-linker itself increase the flame retardancy. The addition of softener not only imparts softness in the treated cotton fabric, but also enhances the strength of finished fabrics.

Keywords- Fabric finishing; fire retardant fabrics; environment friendly cross linkers; fabric softeners; cotton fabrics.

I. INTRODUCTION

Now-a-days, no one can deny with substantial industrial development all over the globe. Here, we cannot ignore a very important aspect related to this generous industrial development which is the safety of human beings who are working in these industries. Today, an increasing prospective of flammable textile materials has ensured the human sanctuary and their affluences. The government along with the textile industries are taking serious steps in the development of modern and advanced techniques to prevent fires and risk mitigation in industries.

In these circumstances, the need of enhancing flame retardancy feature of textile materials is inevitable. Cotton is no doubt, most widely used raw material for the fabric manufacturing thanks to lots of properties such as ease, flexible hand and low cost. Other than its worthwhile properties, cotton products have higher tendency to catch fire and therefore characterized as highly flammable materials. Application of some highly efficient flame retardant finish in right proportion is the sole solution of this problem.

The major proportion of the effective flame retardants contains phosphorous in a broad spectrum while the halogens maximize the effectiveness as well. Ravichandran [1] found that the halogenated flame retardant materials are noxious. Phospholene oxides (a family of composites) is found to be such possible flame retardant substitute to the halogenated flame retardants, available at present.

A combination of adequate binders as well as chemicals in an appropriate share is also vital in order to attain the required degree of flame resistancy. The application of cross linkers contacting Phosphorous helps to improve the tendency of flame retardancy in the cellulosic fabrics. The role of cross linkers is to fix the finishes on fabrics and secondly, requires less time to dry the finishing [2]. Furthermore, the endurance of coating was evaluated by recurring washing with cross linker agent [3].

An absolute flame retardant fabric for textile application must possess conformability, Eco friendliness and cost effectiveness. A loss of tensile properties and air permeability of materials has been recorded as a result of treatment with the durable flame retardants and they contain considerable mass of chemicals as narrated by Nelson [4] the impact of flame retardant finishes in the result of reduction of softness of fibers. The stiffness of fibers is tough to deal with. In this situation, the addition

of softener and catalyst in the mixture of fire retardant finish and cross-linker not only enhance the tensile strength of cotton fabric, but also make it soft and comfortable. Moreover, perfect flame retardant formulation can lead to achieve the high degree of fire resistancy and washing stability.

In this situation, the addition of softener and catalyst in the mixture of fire retardant finish and cross-linker not only enhance the tensile strength of cotton fabric, but also make it soft and comfortable. Moreover, perfect flame retardant formulation can give high levels of fire retardancy and wash stability. After the fire is blown out, char length and afterglow were estimated which implies that the fabric can sustain burning, if it permits this test. The primary objective of vertical flame retardant test is to evaluate the flame resistance property of fire retardant materials. Vertical flammability test permits to appraise several parameters in a row.

Researchers [5-6] explored the performance of distinct flame retardant treatments available at present time and presented the durable flame retardant treatments for cellulosic materials. Pyrovatex is one of the robust flame retardant chemicals.

The focus of this research was to develop such suitable flame retardant formulation for cotton woven fabric which not only contain phosphorous based flame retardant compound, an initiator, a cross linking agent and solvent in right proportion, but also make comfortable, eco-friendly, durable and cost effective fire retardant cotton fabric.

II. MATRIALS & METHODS

1. Materials

Plain woven fabrics made-up of pure cotton were purchased for the study. The chemicals used for the sake of execution of the experimental phase were Pyrovatex as Flame Retardant Finish, Knittex as Cross-linker, Turpex as Softener, Phosphorid Acid and $MgCl_2$ as Catalyst.

2. Application of Finishes

The fire retardant finishes were applied using the standard Pad-Dry method by means of horizontal laboratory padder**.**

100 grams water taken to set the finish pickup at 75%. This was done by setting the padder speed at 2 meter/minute and pressure at 3-PSI. Thirteen different samples of finished fabrics were prepared by using the flame retardant, cross-linker, softener and catalyst in the different ratios as shown in table 1.

The solution was prepared in each case by mixing well with stirrer and poured in between rollers of auto-pad laboratory padder. The fabric samples were passed through the rollers. The value of pickup of laboratory scale padder was set on 75%. After the finish was applied, the samples were allowed to dry at 100 ˚C for 3 minutes and cured at 160 ˚C for 4 minutes for fixation. A laboratory scale oven was used to carry out drying and curing.

Table 1. Finishing Solutions Recipes

Sample #	**Pyrovatex (Flame Retardant)**	**Phosphoric Acid (Catalyst)**	**Knittex (Crosslinker)**	**Turpex (Softener)**	**$MgCl_2$ (Catalyst)**	**Water (g)**
1	20 g	2.2 g	-	-	-	77.8
2	30 g	2.5 g	-	-	-	67.5
3	40 g	2.7 g	-	-	-	57.3
4	20 g	2.2 g	6g	-	-	71.8
5	30 g	2.5 g	7 g	-	-	60.5
6	40 g	2.7 g	8 g	-	-	49.3
7	20 g	2.2 g	6 g	2 g	-	69.8
8	30 g	2.5 g	7 g	2 g	-	58.5
9	40 g	2.7 g	8 g	2 g	-	47.3
10	20 g	2.2 g	6 g	-	0.5 g	72.3
11	30 g	2.5 g	7 g		0.5 g	57
12	20 g	2.2 g	6 g	2 g	0.5 g	70.3
13	30 g	2.5 g	7 g	2 g	0.5 g	55

3. Testing of Physical Properties
The following properties were tested in order to investigate the effect of flame retardant finishes, cross-linker and softener coating on the fabric.

4. Vertical Flammability
In order to measure the vertical flame resistance of the fabrics, Vertical Flammability Test according to standard ASTM D-6413-08 [7] was performed. Each sample was tested three times for both char length and char width.

5. Washing Durability
Washing durability test was carried out to evaluate the changes in fire retardancy of finished cotton fabric when exposed to frequent instinctive laundering procedures. All the samples were washed to number of launderings i.e. 1 washing cycle, 2 washing cycles, 5 washing cycles and 10 washing cycles. For this purpose, automatic washing machine with AATCC standard detergent along with automatic tumble dryer was used. Standard method (ISO 105-C10:2006) for washing [8] was used.

6. Tensile Strength
The tensile strength was determined for all the samples according to ASTM D-5034 [9].

7. Atmospheric Conditions
The testing of samples was carried out in laboratories where standard atmospheric conditions i.e. 65 ± 2% relative humidity and 20 ± 2 ˚C temperature were maintained.

III. Results and Discussion

8. Vertical Flammability
The results of vertical flammability for various combinations of finish concentration, cross-linker were collected from this test and summarized in the graphical form.

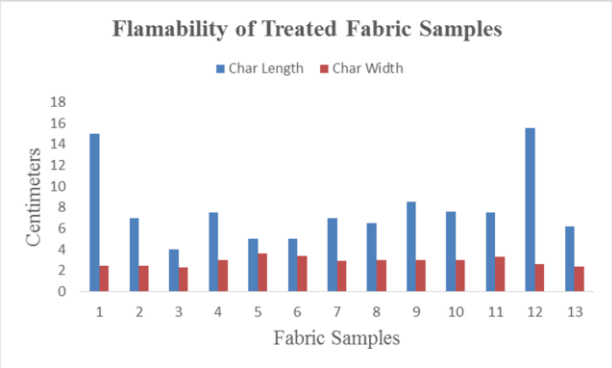

Figure-1. Flammability of treated fabric samples

Fig. 1 represents the results and trend of char length & char width when cotton fabric samples were treated with flame retardant finish, cross-linker and softener under the influence of catalysts at various combinations.
The results for sample # 1, 2 & 3 were obtained after treating the cotton fabric samples with Pyrovatex and Phosphoric Acid which clearly indicated that with an increase in proportion of flame retardant finish (Pyrovatex), the char length and char width decrease. The optimum results were recorded for the fabric treated with 40 grams of flame retardant finish and 2.7 grams of phosphoric acid. The char length decreased from 15 cm to 4 cm and char width decreased from 2.5 cm to 2.3 cm with 20 grams increase in the concentration of flame retardant finish.
Thus, it can be illustrated that a higher proportion of flame retardant in association with the higher proportion of phosphoric acid facilitates in enhancing the flame retardant properties. As Villa and Krasny [10-11] carried out test for vertical flammability on small scale, whereupon a testing technique has been introduced for the char length after flame and glow as well as melt drip to minimize the risk after the expulsion of the ignition source.
When cross-linker was added to the finish solution, the results indicate that the addition of cross-linker itself increase the flame retardancy. The application of cross-linker tends to increase the fabric stiffness; therefore, softeners were added. The addition of softener not only imparts softness in the treated cotton fabric, but also enhances the fire retardancy as described by Liu [12] who remarked that the treated cotton fabrics have shorter after-burn time, shorter char length and no after-flame during the vertical burning test. However, the addition of catalyst ($MgCl_2$) within the mixture of various concentrations of fire retardant finishes with and without softener imparted negative impact upon the fabric in the form of decreasing fire retardancy of fabric.

9. Washing Durability
This test was performed to assess the durability of finishes after repeated washing. The results of sample # 1, 2 & 3 show the trends for flame retardancy of cotton fabric treated with Pyrovatex and Phosphoric acid after 1, 2, 5 & 10 washing cycles.

Table-2. Flammability after repeated washings

Sample #	Flammability Before Washing		Flammability After Washing							
			Washing cycle 1		Washing cycle 2		Washing cycle 5		Washing cycle 10	
	L*	W**	W	L	W	L	W	L	W	L
1	15	2.5	8	20	8	18	8	18	8	18
2	7	2.5	5.8	15.5	5.8	15	8	21	8	21
3	4	2.3	6	11.5	6	17.5	6	17.5	7.8	18.5
4	7.5	3	8	19.3	8	17	7	23	8	17
5	5	3.6	5	16	5.5	16	8	20.5	7.8	21
6	5	3.4	6.5	16	5.7	16	4	16.5	5.5	18
7	7	2.9	4.5	17	8	13	6	19	8	20
8	6.5	3	4.8	15.7	5.8	16.8	7.8	17	8	17
9	8.5	3	4.7	15	2.7	7.3	6	17	8	19
10	7.6	3	8	14.5	6	14.5	8	18.5	8	23
11	7.5	3.3	3.5	9	3.5	8	3.5	19	4	12
12	15.5	2.6	6	14.5	6	14.3	8	17.5	7.8	27
13	6.2	2.4	6	12.5	6.8	15	6.8	23	4.5	14

L*: Char length; W**: Char width

At 20g concentration of flame retardant finish, flame retardancy decreased after 1 washing cycle by increasing the value of char length from 15 to 20 cm and char width from 2.5 to 8 cm. After 2nd washing, flame retardancy of fabric samples slightly increased with decrease in char length from 20 to 18 cm and no change in char width was observed. This trend remains same after 5th and 10th washing cycles. In case of sample # 2, the results indicated a continuous fall in fire retardancy of cotton fabric treated with 30g Pyrovatex after 1st, 2nd and 5th washing by increasing the value of char length from 7 to 15.5, 15 and 21 cm as well as char width from 2.5 to 5.8, 5.8 and 8 cm respectively. Later on, there remains no difference between the results of 5th and 10th washing as studied by Muralidhara and Sreenivasan [13-14] who reported that the effect of flame retardant decreased after treated fabrics washed for 3 frequent cycles.

With addition of cross-linker within the solution of various concentration of flame retardant finish, the trend of decreasing the fire retardancy remain same after 1st, 2nd, 5th and 10th washing cycles. Again, the trend of sudden decrease in fire retardancy after 1st washing never altered for all samples. These results are in accordance with Bischof and Katović [15] who remarked that phosphorus containing catalyst enhances the fire retardant property of the durable several washing cycles. The addition of $MgCl_2$ catalyst with and without softener in the mixture of various concentration of flame retardant finish could not change the trend of decreasing fire retardancy of cotton samples after successive washings.

10. Tensile Strength

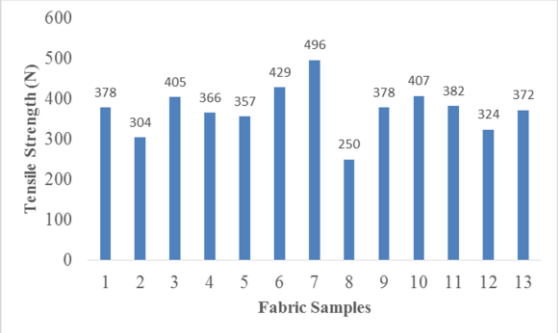

Figure-2. Tensile strength of finished fabric samples

The Fig. 2 shows the effect of various combinations of fire retardant finishes on tensile strength of fabric samples. By increasing the concentration of Pyrovatex (flame retardant finish) from 20 to 40 g, tensile strength increased from 378N to 405N. Whereas, by adding Knittex (Cross-Linker), tensile strength of fabric decreased at 20g Pyrovatex however, a steep increase was observed by enhancing the concentration of Pyrovatex up to 40g. The value of tensile strength recorded highest (496N) when Turpex (Softener) was added at 20g Pyrovatex and lowest up to 250N at high concentration of Pyrovatex i.e. at 30g after addition of 2g Turpex (Softener).

This trend remained same when $MgCl_2$ was added in various concentration of fire retardant finish without softener.

However, with addition of Turpex in the mixture of Pyrovatex, Phosphoric Acid, Knittex and $MgCl_2$, the inverse trend was observed. The value of tensile strength decreased at lower concentration of Pyrovatex.

IV. CONCLUSION

In this study, flame resistance of different combinations of flame retardant finishes on cotton fabrics were compared. The vertical flammability test was conducted to determine the effect of the various combinations of additives. In order to assess the durability of finishes to washing, treated fabric samples were washed repeatedly and flammability was observed. Tensile strength is directly proportional to the concentration of fire retardent finish. It was concluded with the increasing concentration of flame retardant and phosphoric acid the flame resistance increased. Furthermore, the addition of cross-linker to the finish solution also increased the flame retardancy. However, decrease in flame resistance was observed after multiple washings. The softener though, not only imparted softness in the treated cotton fabric, but also enhanced the fire retardancy.

REFERENCES

[1] S. Ravichandran, R.M. Bouldin, J. Kumar and R. Nagarajan, 2011, A Renewable Waste Material for The Synthesis of a Novel Non-Halogenated Flame Retardant Polymer, J. Clean. Prod., 19(5), pp. 454-458.

[2] F. Lessan, M. Montazer and M.B. Moghadam, 2011, A Novel Durable Flame-Retardant Cotton Fabric Using Sodium Hypophosphite, Nano Tio2 and Maleic Acid, Thermochim. Acta, 520(1), pp. 48-54.

[3] J.B. Dahiya and K. Kumar, 2009, Flame Retardant Study of Cotton Coated with Intumescents: Kinetics and Effect of Metal Ions, J. Sci. Ind. Res., 68, pp. 548-554.

[4] G. Nelson, 2002, Application of Microencapsulation in Textile, Int. J. Pharm., 242(1), pp. 55-62.

[5] A. R. Horrocks, B. K. Kandola, P. J. Davies, S. Zhang and S.A. Padbury, 2005, Developments in Flame Retardant Textiles–A Review, Polym. Degrad. Stab., 88(1), pp. 3-12.

[6] Khanh, V. T. Hong and N. T. Huong, 2019, Influence of crosslinking agent on the effectiveness of flame retardant treatment for cotton fabric, Ind. Textila, 70 (5), pp.413-420.

[7] ASTM, 2008, Standard Test Method for Flame Resistance of Textiles (Vertical Test), Designation 6413-08, Annual book of ASTM standards, ASTM International, West Conshohocken PA, U.S.A.

[8] ISO, 2006, Textiles-Tests for Colour Fastness-Part C10: Colour Fastness to Washing with Soap or Soap and Soda, International Organization for Standardization (ISO) 1, ch. de la Voie-Creuse, Case postale Geneva 20, Switzerland.

[9] ASTM, 2010, Standard Test Method for Breaking Strength and Elongation of Textile Fabrics, Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA, United States.

[10] M.V. Kay and J.F. Krasny, 1990, Small Scale Vertical Flammability Testing for Fabrics, Fire Saf. J., 16(3), pp. 229-241.

[11] N. T. Huong, V.T. Khanh, & N. P.D. Linh, 2021, Optimizing content of Pyrovatex CP New and Knittex FFRC in flame retardant treatment for cotton fabric. Industria Textila, 72(3), pp. 315-323.

[12] W. Liu, L. Chen and Y.Z. Wang, 2012, A Novel Phosphorus-Containing Flame Retardant for The Formaldehyde-Free Treatment of Cotton Fabrics, Polym. Degrad. Stab., 97(12), pp. 2487–2491.

[13] K.S. Muralidhara and S. Sreenivasan, 2010, Thermal Degradation and Burning Behaviour of Cellulose Based and Cellulose-Silk Blended Upholstery Fabrics, J. Sci. & Ind. Res., pp. 879-885.

[14] D. Xu, S. Wang, Y. Wang, Y. Liu, C. Dong, Z. Jiang, and P. Zhu, 2020, Preparation and Mechanism of Flame-Retardant Cotton Fabric with Phosphoramidate Siloxane Polymer through Multistep Coating, Polymers, 12(7), 1538.

[15] D. Katović, S.F. Grgac, S.B. Vukušić and A. Katović, 2012, Formaldehyde Free Binding System for Flame Retardant Finishing of Cotton Fabrics, Fibres Text. Eas. Eur., 20(1), pp. 94-98.