Flame Resistance of Chemical Protective Clothing Materials at Various Washing Intervals

M. Ijaz[1], S. Kalsoom[2], N. A. Akthar[3]

[1]Lahore College for Women University, Lahore, Pakistan
[2]Govt. College of Home Economics Lahore, Pakistan
[3]University of Engineering and Technology, Taxila, Pakistan
[1]mehreenijaz@hotmail.com

Abstract—The study investigates the fire resistance of chemical protective clothing materials over repeated number of washing cycles. This research work was experimental in nature, performed and completed at a reputable textile mill. The sample of protective coveralls was collected from fertilizer-manufacturing units. These coveralls were evaluated for their fire-resistant ability through the determination of after-flame time and char length by following Vertical Flame Test ASTM D 6413. An experimental fabric was manufactured with various construction parameters to improve the results. Data was presented in the form of mean±S.D along with their minimum and maximum value. The results of experimental and existing clothing materials were compared. The conclusion drawn from this study was that the existing clothing materials failed to meet the international requirements and their condition became even worse with the repeated washing. Whereas, experimental clothing material performed well even with repeated laundering. These findings can be helpful for the manufacturers to review and alter the construction parameters to develop protective coveralls for the safety of workers.

Keywords—Protective Clothing, Fire Resistance, After-Flame Time, Char length, Washing Cycles.

I. Introduction

In a typical setup at a chemical industry, workers are threatened by toxic chemicals, fumes or gases. These threats may cause severe injuries and casualties [i]. Number of different chemicals is used in different industries. Behavior, nature and reaction of chemicals vary so much that safety becomes a cumbersome task. However, considering the serious nature of threats, safety measures become pertinent [ii]. Industries in both, public and private sector need protective clothing for safeguarding their employees against such hazards. Accurate protective ensembles can help the wearer to get a few extra seconds of escape [iii].

Chemicals when exposed to different atmospheric conditions or other chemicals, may respond in the form of a chemical reaction. Nature of chemical reaction depends on number of factors such as temperature and types of participating chemicals. In an industrial setup, such chemical reactions are routine; small sparks or temperature-change may result in big fire. Ignition, fuel and oxygen are necessary elements for a fire. Therefore presence of toxic chemicals with plenty of oxygen in a chemical industry poses fire-hazard-threats. Fire never burns at the same rate/speed. Some fuels burn quickly and others burn slowly. Chemical composition, amount and available oxygen affect the speed of burning [iv].

The chemical structure of fibers determines its behavior under given conditions. Chemical behavior determines the flammability of yarns and fabrics. For example, fibrous polymer, a thermally stable polymer, has high decomposition temperature and its decomposition reaction is endothermic in nature [v]. Flammability refers to the ease with which a substance may ignite and support a fire. In order to reduce flammability and/or reduce speed of fire, chemicals known as flame-retardants are applied on a flammable materials such as textiles and plastics [vi-vii]. These flame-retardants can be added in the spinning solution for making the yarns or applied on the surface of textile materials to make them resist fire and prevent the burning process [viii]. Compounds of sulfuric and phosphoric acid are usually used as flame retardant for cellulosic and synthetic polymers in textile manufacturing. Phosphoric acid forms a layer of char, which acts like boric acid, borax and hydrated aluminum oxide. It is mostly used in combination with nitrogen. These combinations are effectively used for natural and synthetic textile materials such as cellulose, polyurethane and polyester [iv].

Flammability of fabrics is evaluated based on the nature of burning hazard and fabric's ability to self-extinguish. Self-extinguishing fabric stops burning when flame is removed. The flammable fabric starts burning when exposed to an ignition source for a time period of up to 12 seconds and continues to burn even when flame is removed [v].

Flame-retardant fabrics are designed to resist ignition when exposed to a flame. Flame-retardant fabrics are of two types: inherently and treated flame-retardant fabrics. Inherently flame-retardant fabrics such as aramids have the property of resisting fire without use of additives. This makes them durable even after laundering processes [ix]. Treated flame-retardant fabrics are processed chemically to induce flame-resistant characteristics. They can also be manufactured by laminating or coating of additives on the surface of fabric. These coatings may lose their strength with laundering process [x]. Determining the effect of laundering on the performance of protective-clothing ensembles involves deep understanding of fabric construction parameters, its geometry, stability as well as the forces that hold within the fabric [xi].

II. Materials and Methods

A total of fifteen chemical protective coveralls (locally-made) were randomly obtained from the fertilizer-manufacturing units and evaluated for their ability to resist fire. The coveralls were categorized into three groups (100% polyester, 100% cotton, and blend of cotton/polyester) based on their fiber content and irrespective of their brand names. The construction specifications of these coveralls are given in the Table I

TABLE I

CONSTRUCTION SPECIFICATIONS OF EXISTING PROTECTIVE COVERALLS

Group	Sample Code	Fiber Content	Fabric Weight (GSM)	Thread Count (per inch)	Linear Density (tex)	
					Warp Direction	Weft Direction
Polyester	P1	Polyester 100%	153	216	17.216	17.938
	P2	Polyester 100%	151	160	18.746	18.981
	P3	Polyester 100%	152	104	36.575	35.542
	P4	Polyester 100%	160	125	15.254	15.968
	P5	Polyester 100%	210	165	29.525	29.525
Cotton	C1	Cotton 100%	257	228	26.599	26.362
	C2	Cotton 100%	208	170	28.946	29.233
	C3	Cotton 100%	141	190	13.451	12.564
	C4	Cotton 100%	223	184	26.013	35.572
	C5	Cotton 100%	143	224	14.726	15.064
Blends	B1	Cotton 97% Polyester 3%	264	142	13.921	14.351
	B2	Cotton 98% Polyester 2%	215	133	15.743	16.236
	B3	Rayon 70% Polyester 30%	145	171	16.53	16.932
	B4	Cotton 95% Polyester 5%	221	136	13.301	15.321
	B5	Cotton 45% Polyester 55%	146	140	19.949	18.806

The samples were laundered by following AATCC Monograph M6 [xii] with front loading machine at a speed of 45±10 rpm. They were washed at 54±2.9°C for about 11±1 minutes while 0.1g/liter ECE reference detergent was added into the machine. The samples were rinsed for about 2 minutes during the first rinsing cycle and for 5 minutes during second rinsing cycle by adding liquid softer. The spinning was carried out at 1300±150 rpm for about 12 minutes. They were tumble dried at 68±6°C for 1.5 hours. All samples of protective coveralls were given 20 laundering cycles. After every 5 cycles, their ability to resist fire was evaluated by conducting Vertical Flame Test ASTM D 6413 [xiii].

Five specimens in lengthwise direction were taken with the measurement of 76mm x 300mm. They were brought to the moisture equilibrium according to the specifications of ASTM-D1776 test method [xiv]. After removing specimen from standard atmosphere, it was exposed to flame within 4 minutes. Test specimen was held by a holder; two clamps at top and two clamps at the bottom of the holder held specimen very tightly. Holder along with the test specimen was inserted into the cabinet; inside the cabinet, burner was placed 19mm below the specimen. The timer for flame was set and the specimen was exposed to it for 12 ±0.2 second. It was noted for its melting or dripping behaviour. In order to note the after-flame time, stop watch was immediately started as soon as the holder along with specimen was removed from the cabinet. Once holder was removed, specimen was allowed to cool down. The char length was measured by making a crease in the specimen through peak of charred area and parallel to the specimen sides.

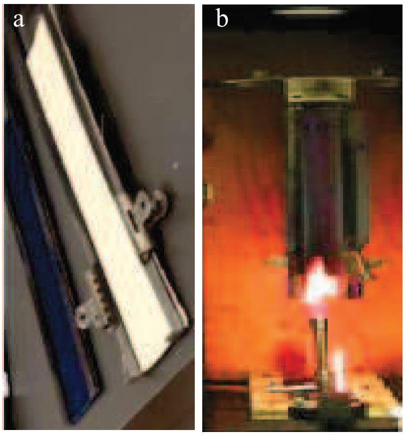

Fig. 1. (a). Samples clamped in the holder (b) Fire tester

In addition to testing existing fabrics, an experimental fabric was manufactured at a reputable textile mill with the aim of achieving better results. A woven fabric was manufactured using ring spun yarns. Inner layer of this fabric was made of a Polyester-Cotton (65 / 35) blended yarn which was treated with a fire retardant agent (FPK 8001). Linear density (warp and weft) was fixed at 19.68 tex. Aramid yarn with a linear density of 15.06 tex for both warp and weft directions was used for the outer layer. Finally plain weave was followed for the interlacing of yarns to make a fabric. The fabric density was 60 ends (per inch) and 5 picks (per inch).

Fabric weight was 135 GSM. According to the of the sample loom, length and width of the prepared fabric was 236 x 19 inches. The construction specifications of the experimental fabric are given in Table II.

TABLE II

CONSTRUCTION SPECIFICATIONS OF EXPERIMENTAL FABRIC

Linear density (Polyester / Cotton blend)	Linear density (Aramid)	Weight	Fabric density (ends/picks)	Thread Count	Length /Width
19.68 tex	15.06 tex	135 GSM	60/55 per inch	115	236 x 19

Lastly, following the same test methods used while testing existing fabrics, this new fabric was laundered and evaluated for its fire-resistance characteristics.

III. Results and Discussion

Table III describes descriptive statistics of all three groups for their after-flame time and char length. The mean value of after-flame time for polyester was recorded at 15.24±0.96 for zero wash and it increased to 48.81±1.13 for 20th wash. After-flame time for Cotton was noted at 6.87±0.36 for zero wash and it increased to 44.69±0.92 for 20th wash. Similarly, mean after-flame time for blend of cotton / polyester was recorded at 14.95±0.93 for zero wash and increased to

TABLE III
FLAME-RESISTANT ABILITY OF EXISTING PROTECTIVE CLOTHING

Washing Cycles	Specimen		After-Flame Time (Seconds)				Char length (Inches)			
		N	Mean	S.D	Min.	Max.	Mean	S.D	Min.	Max.
0	Polyester	5	15.24	0.96	14.20	2.93	2.45	0.50	3.46	2.93
0	Cotton	5	6.87	0.36	6.50	2.49	2.20	0.42	2.98	2.49
0	Blend	5	14.95	0.93	14.10	3.28	3.20	0.10	3.40	3.28
5	Polyester	5	21.82	1.14	20.70	7.39	7.28	0.13	7.54	7.39
5	Cotton	5	15.93	0.95	15.00	5.64	5.40	0.34	6.04	5.64
5	Blend	5	26.09	1.75	24.50	8.68	7.40	1.89	10.86	8.68
10	Polyester	5	34.81	0.91	33.90	9.37	8.10	2.17	11.86	9.35
10	Cotton	5	28.42	1.28	27.40	8.34	7.20	1.48	10.02	8.34
10	Blend	5	33.59	1.62	32.20	9.35	8.90	0.41	9.70	9.37
15	Polyester	5	43.14	2.74	40.10	10.06	9.10	0.94	10.98	10.06
15	Cotton	5	42.85	0.64	42.30	10.06	8.90	1.32	11.50	10.06
15	Blend	5	45.38	1.34	44.20	11.56	10.80	0.66	12.00	11.56
20	Polyester	5	48.81	1.13	47.64	11.13	10.00	1.02	12.00	11.13
20	Cotton	5	44.69	0.92	43.88	10.83	10.00	1.04	12.00	10.83
20	Blend	5	47.64	0.43	47.14	11.73	11.20	0.46	12.00	11.73

47.64±0.43 for 20th wash. Results clearly show that after-flame time rises with increase in number of washing cycles for existing clothing coveralls. The mean value of char length for polyester was recorded at 2.45±0.50 for zero wash and increased to 10.00±1.02 for 20th wash. Charlengthfor cotton was recorded at 2.20±0.42 for zero wash and increased to 10.00±1.04 for 20th wash. Char length for blended fabric was recorded at 3.20±0.10 for zero wash and 11.20±0.46 for 20th wash. There is an increase in char length of existing materials with repeated number of washing cycles.

Lastly, following the same test methods used while testing existing fabrics, this new fabric was laundered and evaluated for its fire-resistance characteristics.

RESULTS AND DISCUSSION

Table III describes descriptive statistics of all three groups for their after-flame time and char length. The mean value of after-flame time for polyester was recorded at 15.24±0.96 for zero wash and it increased to 48.81±1.13 for 20th wash. After-flame time for Cotton was noted at 6.87±0.36 for zero wash and it increased to 44.69±0.92 for 20th wash. Similarly, mean after-flame time for blend of cotton / polyester was recorded at 14.95±0.93 for zero wash and increased to 47.64±0.43 for 20th wash. Results clearly show that after-flame time rises with increase in number of washing cycles for existing clothing coveralls. The mean value of char length for polyester was recorded at 2.45±0.50 for zero wash and increased to 10.00±1.02 for 20th wash. Charlengthfor cotton was recorded at 2.20±0.42 for zero wash and increased to 10.00±1.04 for 20th wash. Char length for blended fabric was recorded at 3.20±0.10 for zero wash and 11.20±0.46 for 20th wash. There is an increase in char length of existing materials with repeated number of washing cycles.

Table IV describes descriptive statistics of experimental fabric for its after-flame time and char length. The after-flame time was noted at 0.56±0.05 for zero-wash and increased to 0.86±0.05 for 20th wash. The char length was recorded at 0.50±0.10 for zero wash and increased to 0.63±0.25 for 20th wash.

TABLE IV
FLAME-RESISTANT ABILITY OF EXPERIMENTAL FABRIC

Washing Cycles	After-Flame Time (Seconds)				Char length (Inches)			
	Mean	S.D	Min.	Max.	Mean	S.D	Min.	Max.
0	0.56	0.05	0.50	0.60	0.50	0.10	0.40	0.60
5	0.56	0.05	0.50	0.60	0.50	0.10	0.40	0.60
10	0.60	0.10	0.50	0.70	0.53	0.15	0.40	0.70
15	0.80	0.10	0.70	0.90	0.56	0.15	0.40	0.70
20	0.86	0.05	0.80	0.90	0.63	0.25	0.40	0.90

Figure 2 shows after-flame time of existing and experimental clothing materials. This graph clearly depicts that after-flame time (in seconds) of existing materials increased with every washing cycle whereas, experimental fabric had not significant increase in its after-flame time even at 20th wash. According to the test procedure specifications, after-flame time should not exceed 2 seconds. It was observed that all the three groups of existing materials failed to meet safety standards in regards to protection against fire. Coveralls from the cotton group performed better at zero wash as compared to the other two groups. Experimental fabric recorded after-flame time of less than 2 seconds even at 20th wash. Thus experimental fabric meets the safety standards.

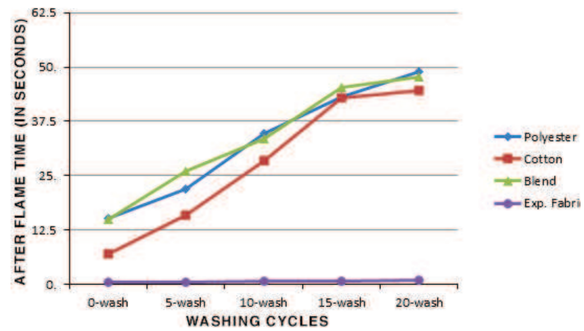

Fig. 2. After-flame time of experimental and existing clothing materials

Figure 3 illustrates char length of existing and experimental clothing materials. This graph clearly shows that char length (in inches) of existing materials increased at a significant rate as the number of washing cycles increased from zero to twenty. On the other hand, experimental fabric had no significant increase in its char length over repeated washings. According to the test method specifications, char length of test specimen should not exceed more than 4 inches. At zero wash, all existing materials passed this test specification. However, with increasing number of washing cycles, their performance dropped drastically. Coveralls from cotton group exhibited better performance than the other two groups but these coveralls also failed to meet 4 inches barrier with increasing number of washing cycles. Experimental fabric recorded a char length of less than 4 inches even at 20th wash. Thus, it passed this test.

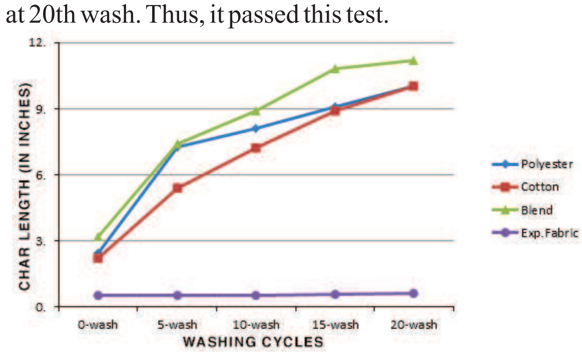

Fig. 3. Char length of experimental and existing clothing materials

One possible reason for poor performance of existing materials was the use of inferior quality finishing, which easily cracked and lost its strength after laundering. It was also highlighted by [xv] that when finish breaks out from the outer layer, it exposes the inner layer directly to the flame. The nature and kind of finish is very important in manufacturing fire-resistant fabrics. As explained by [xvi], cotton and a blend of cotton/ polyester fabrics burn within few seconds and continue ignition until the whole sample is consumed. Polyester fabrics melt and burn easily, if no finish is applied over their surface. Experimental fabric passed the test based on international safety standard because of inherent flame-resistant characteristics of Aramid fiber. On exposure to fire, these fibers swell up and make a barrier between source of ignition and human body. This barrier lasts till it cools thus provides few precious seconds to the wearer to escape [vi]. Moreover, a blend of polyester/cotton yarn was given a flame retardant treatment that did not break even at 20th wash. It was highlighted by [xvii] that an aramid layer in combination with flame-retardant fabric provides better protection to the wearer.

V. Conclusion

Chemical Protective clothing safeguards it wearer from fire hazards. It was concluded that none of the collected sample was able to perform well against fire hazards according to the international test standards. Furthermore, ability of the coveralls to withstand against ignition deteriorated with laundering. Considering the threats posed by chemicals in an industry, high quality protective clothing should be worn by the workers which maintain its performance even after repeated use and laundering. The experimental clothing material met these requirements, as mentioned in international safety-standards. Correct selection of fibers and finishing treatment played a vital role in manufacturing standard-compliant protective clothing.

References

[I] M. Raheel, “Chemical protective clothing”, in Protective clothing systems and materials, vol. 25, New York, CRC Press, 1994, pp.39-78.

[ii] Z. N. Jaspal, and N. Haider, “Management of Chemicals in Pakistan: Concerns and challenges”, Research Journal of South Asian Studies,vol. 29, no. 2, pp.497-517, Dec. 2014.

[iii] T. E. Neal, and S. L. Lovasic, “Industrial Flash Fire and Burn Injury Fundamentals with an Instrumented Manikin Demonstration of Protective Clothing Performance”, in ASSE Professional Development Conference and Exposition., American Society of Safety Engineers, Nashville, Tennessee, 2002.

[iv] C. Stephanie, “Retarding the flame”, http://www.selah.k12.wa.us/soar/sciproj2002/StephanieC.html, 2002.

[v] S. Nazare and A.R. Horrocks, “Flammability testing of fabrics”, in Fabric testing, H. Jinlian,Ed.vol. 76, New York, CRC Press, 2008, pp.339-385.

[vi] A. Grad, (2013, April). “Specialist work clothing” [online]. Avaliable: http://specialistworkclothing.wordpress.com/2013/04/29/understanding-flame-retardant-fabrics-nomex-cantex-and-proban/].

[vii] A. Pettigrew, “Halogenated flame retardants”, in Kirk Othmer‘s Encyclopaedia of Chemical Technology, New York:John Wiley and Sons, 1993.

[viii] T. U. Onuegbu, E.T. Umoh and I.E. Iwuchukwul, “Flame retardant effects ON flexible polyurethane foam treated WITH potassium aluminum sulphate”,ARPN Journal of Science and Technology, vol. 2, no.11, pp.1097-1102, Dec. 2012.

[ix] “Fire retardant clothing requirements for welders and cutters. Workers Compensation”, Sep. 2012. [online]. Available: www.wcb.pe.ca/.../Document/pub_fireretardantclothingrequirements.pdf

[x] W. Zhou, N. Reddy and Y. Yang, “Over view of protective clothing” in Textiles for protection, R. A. Scott, Ed. Cornwall, Woodhead publishing limited, 2005, pp.3-25.

[xi] B. Hepworth, “Investigating the dimensional Properties of 1x1 Rib Fabrics” Knitting International, 48-51, July. 1989.

[xii] Standardization of home laundry test conditions, AATCC Monograph M6, 2013.

[xiii] Standard test method for flame resistance of textiles (Vertical test), ASTM D6413, 2013.

[xiv] Standard practice for conditioning and testing textiles, ASTM D1776, 2015.

[xv] H. Makinen and S. S. Mustonen, “Comparing the flammability of fabrics in accordance with EN 531 and ENV 50354, International Journal of Occupational Safety and Ergonomics, vol. 10, no. 3, pp.207-213, July. 2004.

[xvi] Sellers, R. D., & Carr Jr, V. J. (2007). Performance of Nomex Military Uniforms in Attacks by Flame Field Expedient Weapons-A Literature Study. Applied Research Associates, Technical Report, Mar. 2007.

[xvii] M. W. King, X. Li, B. E. Doupe and J. A Mellish, “Thermal protective performance of single layer and multiple layer fabrics exposed to electrical flashovers”, in Performance of protective clothing, S. Z Mansdorf, R. Sagar and A. P Nielsen, Eds. Baltimore, American Society for Testing and Materials, 1988.