PENETRATION AND REPELLENCY OF CHEMICAL PROTECTIVE COVERALLS

M. Ijaz, S. Kalsoom[*] and N.A. Akthar[**]

Department of Home Economics, Lahore College for Women University,
[*]Department of Textiles and Clothing, College of Home Economics, Lahore,
[**]University of Engineering and Technology, Taxila, Pakistan
Corresponding author's e-mail: mehreenijaz@hotmail.com

ABSTRACT: Present study was to evaluate chemical penetration and repellency of locally manufactured protective coveralls used by the workers of fertilizer manufacturing units. The research was based on laboratory work performed and completed at Dyeing and Finishing Unit, Nishat Mills Limited. The samples were evaluated for their chemical resistance at various laundering intervals by ISO 6530:2005 test methods. Chemical penetration and repellency of three different fabrics were tested against four different chemicals. The results showed that all the samples were unable to resist chemical attack and their condition, became even worse with repeated washing cycles. At 20th washing cycle, 98.5% chemicals penetrated synthetic fiber (polyester) whereas chemical penetration for blended fiber was recorded at 98.9% and for natural fibers was recorded at 99.1%. Similarly chemical repellency for natural and synthetic fiber was recorded at 0% whereas for blended it was recorded 1at 0.4%. According to the test results, out of all the three samples, synthetic fiber performed better against chemical attacks.

Key words: Chemical Penetration, Chemical Repellency, Protective Coveralls and Laundering Intervals.

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INTRODUCTION

Chemicals used in the industry are dangerous for human body. Workers dealing with chemicals should use protective clothing against toxic chemicals. There is no known fabric or fiber that gives 100% protection against all hazardous chemicals (Zhang and Raheel, 2003). Liquid chemicals may penetrate in protective clothing and come in contact with human skin. This contact, based on nature of chemical, can be highly dangerous to human life. (Ibrahim and Mahmoud, 2013; and Barker, 2005).

Accidents at the work place are dreadful disasters. Many workers are exposed to hazardous chemicals in local industries on daily basis. Attempts must be made to safeguard workers from dangers (Ahsan and Partanen, 2001). More than ninety percent industrial staff working in such indoor settings is at the risk of being exposed to explosive chemicals (Barro *et al*., 2009)

Most of the chemicals badly affect human skin upon exposure. It may lead to irritation, disability or even death depending on the severity of chemicals (National Institute of Justice, 2002). Hydrofluoric acid with more than seventy percent concentration is very dangerous; five percent skin burn from fluoride ion may lead to death. Similarly coal tar does not present an imminent threat but can cause skin cancer (Mansdorf, 2011).

Permeation is the ability of a chemical to pass through the protective fabrics. It includes the chemical absorption at material surface level, dispersion through the polymer and then desorption of a chemical from the inner surface of fabrics. It is influenced by various factors such as structure of a fiber, nature of chemical, physical characteristics of fabrics, reaction of a chemical with fiber etc.(Aminabhavi *et. al*., 1989). Breakthrough time plays a vital role in the determination of chemical resistance through the fabric. It is the time between the initial contact of a liquid chemical at outer surface and the recognition of that liquid chemical at inner surface of a fabric. This helps to assess the compatibility of fabric with the chemical. A change in temperature or pressure can cause an effect on the permeation behavior of fabrics as a small increase in temperature may bring a significant decrease in breakthrough time and deteriorate the barrier characteristics of protective clothing (Florus and Otrisal, 2012). Long breakthrough time is an indicator of better resistance of fabrics against hazardous chemical attacks (Krzeminska and Rzymski, 2011). Permeation is greatly affected by the mass and thickness of clothing materials. (Krzeminskaa and Rzymski, 2013andKirsteins, 1991).Multilayered fabrics are better equipped to provide protection against chemicals by adding thickness to the clothing materials (EHS, 2008).

Penetration and repellency are the key factors of chemical resistant characteristics of any clothing material. Penetration is a process in which chemical passes through seams, pores, zippers or other weaknesses of fabric which can be prevented by the proper manufacturing of clothing items (Lee and Obendorf, 2008). A chemical repellent material can be ineffective if it is ragged, ripped or have cuts due to poor making.

Repellency refers to the ability of a fabric to resist absorption. Fabric construction techniques can affect the penetration and repellency percentage of clothing materials (ASTM, 2010 and Barker, 1986).

The primary objective of the present study was to determine how chemical protective clothing behaves when exposed to liquid chemicals. This objective was achieved by studying the chemical repellency and penetration. Thus this information plays a vital role in manufacturing and developing protective clothing.

MATERIALS AND METHODS

Chemical protective coveralls (n=15) locally manufactured were randomly collected from fertilizer manufacturing units and tested for their chemical resistance characteristics. The coveralls were categorized into three groups according to their fiber content irrespective of their brand names Table-1. The coveralls were labelled and evaluated for their chemical penetration and repellency at different laundering intervals.

The collected samples were laundered following AATCC test method (AATCC, 2013). All the samples were given 20 laundering cycles. After every five cycles, coveralls were assessed for their penetration and repellency behavior by following ISO 6530:2005, 'Gutter test' (ISO, 2005).

Chemical solutions were prepared with Sulphuric acid (30% dilution), Sodium Hydroxide (30% dilution), Xylene (undiluted) and Butanol (undiluted) at 20°C to measure the penetration and repellency *of* the fabric samples. Test specimens of 360 x 235 mm were cut out from the samples to make a top layer. Absorbent paper supported by plastic sheet served as the collector layer. The layers were separately weighed before testing and clipped to a gutter inclined at 45 degrees. A beaker was placed at the bottom of the gutter to collect the chemicals spilled from the surface of test specimens. A chemical solution of 10mL was poured off for 10 seconds over the fabric surface. Extra chemical, not retained by the test assemblage, was collected in a beaker. After 60 seconds, top layer and collector layer were weighed separately.

The weight gained in the specimen was recorded in the form *of* retention percentage. The amount of chemical in the collector layer was recorded in the form of penetration percentage. Whereas, the total amount collected in the beaker was recorded in the form *of* repellency percentage. The fabric specimens were evaluated according to their repellency and penetration percentages against each chemical. Protective clothing material that passed performance level 3 for repellency index and performance level 2 for penetration index against at least one of the four chemicals was considered to be an acceptable material for manufacturing chemical protective clothing.

The penetration and repellency percentages were calculated using the following formulas.

Penetration (P) = Mp x 100 / Mt

- Mp was the amount of chemical left on an absorbent paper.
- Mt was the amount of chemical discharged on the fabric specimen.

Repellency (R)= Mr x 100 / Mt

- Mr was the amount of chemical collected in the beaker.
- Mt was the amount of chemical discharged on the fabric specimen.

RESULTS AND DISCUSSION

Penetration or permeation of certain hazardous chemicals (both in liquid or vapour form) through the human body was a major threat to the safety of many industrial workers. This led to the development of protective clothing using various fabrics. Protective clothing should be evaluated for its performance characteristics in order to safeguard the wearer from many hazards (Krzeminska and Rzymski, 2011). Durability and resistance-against-chemicals of protective-clothing materials must meet safety criterion. After testing the penetration and repellency of all specimens against various chemicals, Table-3 it was observed that penetration of liquid chemicals increased with each washing interval. Whereas, repellency of these specimens against tested chemicals decreased at every washing interval. This fact was also supported by Leonas (1998), who studied the effect of laundering on liquid penetration of surgical gowns. It was reported that laundering increased the porosity of fabrics and the open pores in the structure of fiber allowed liquid to pass through it with ease. Differences may occur due to varying manufacturing process and construction parameters such as type of fiber, yarn and coating.

It was clearly observed that synthetic and blended fabrics performed well at zero wash. However as the number of washing cycles increased, their penetration was also increased. Whereas, fabrics made with natural fiber showed poor performance even at the zero wash. It was very clear from the results that all the chemicals, almost completely penetrated these fabrics at 20^{th} washFigure-1. Increase in number of laundering cycles increased the penetration. The porous fabrics can be easily penetrated by the chemicals as liquid or vapour pass through the inner pores of the substrate (Barker, 2005). The molecules of these chemicals permeate into the structure of fibers and lamination or coatings applied on the fabric surface. Thus reducing the repelling power of fibers. It largely depends on the nature of exposure to a particular chemical, contact time and laundering procedure.

According to the AATCC, acceptable penetration index is less than 5 percent for at least one of the tested chemicals. All the samples failed to pass this criterion of penetration index. Major reason for this failure was that no chemical resistance treatments were applied to these samples. It was also noted that these samples were not suitable for resisting chemicals. Another reason for failure was that these samples were made of a single layer fabric. Multiple layers in fabrics help to give protection against toxic chemicals because it takes longer time to penetrate through thicker fabric as compared to the single-layered or thinner fabric (Krzeminskaa and Rzymski, 2013).

It was observed that synthetic and blended fabrics displayed better results at zero wash. However their repellency percentage decreased with increasing number of washing cycles. Whereas, fabrics made with natural fiber performed poorly even at the zero wash. There was a decreasing trend in repellency of all the samples with increasing number of laundering cycles (Fig. 2).

According to AATCC, acceptable repellency index is 95 percent, for at least one of the tested chemicals. It was noticed that all the samples failed to pass this criterion of repellency index. George and Thomas (2001) reported that polymer type was an important factor that influenced the permeation characteristics. Ibrahim and Mahmoud (2013) studied that manufacturing variables such as type of fiber and blending ratios affect the penetration and repellency behavior of a manufactured fabric.

Lower quality of fabric used to manufacture these samples was major reason for their failure. Lack of lamination and coating on these samples affected their performance. Importance of lamination and coating materials used in manufacturing chemical protective clothing was highlighted by Laamanen and Meinander (1996). Substandard lamination or coating procedures resulted in poor bonding with the fabric surface. Poor bonding easily cracks up and allows the chemical to penetrate through the fabric. Effects of substandard lamination and coating were emphasized by Fung (2002). In a study Leonas (1998) reported that non uniform coating on the surgical gowns allowed penetration of liquids through the fabric.

Table 1: Construction particulars of collected protective coveralls.

Sample Code	Fiber Content	Fabric Weight	Thread Count	Linear Density	
				Warp Direction	Weft Direction
A1	Polyester 100%	153	216	17.216	17.938
A2	Polyester 100%	151	160	18.746	18.981
A3	Polyester 100%	152	104	36.575	35.542
A4	Polyester 100%	160	125	15.254	15.968
A5	Polyester 100%	210	165	29.525	29.525
B1	Cotton 100%	257	228	26.599	26.362
B2	Cotton 100%	208	170	28.946	29.233
B3	Cotton 100%	141	190	13.451	12.564
B4	Cotton 100%	223	184	26.013	35.572
B5	Cotton 100%	143	224	14.726	15.064
C1	Cotton 97%Polyester 3%	264	142	13.921	14.351
C2	Cotton 98% Polyester 2%	215	133	15.743	16.236
C3	Rayon 70% Polyester 30%	145	171	16.53	16.932
C4	Cotton 95% Polyester 5%	221	136	13.301	15.321
C5	Cotton 45% Polyester 55%	146	140	19.949	18.806

Table 2: Penetration and repellency criteria of liquid chemicals.

Performance Level	Repellency Index (%)	Penetration Index (%)
3	95	<1
2	90	<5
1	80	<10

Table 3: Penetration and repellency index of all specimens

Washing Cycles	Specimens		Sulphuric Acid		Sodium Hydroxide		Xylene		Butanol	
		N	**P**	**R**	**P**	**R**	**P**	**R**	**P**	**R**
0	Synthetic	5	20.8	76.2	21.6	75.8	23.6	74.3	25.1	70.9
0	Natural	5	90.6	5.9	91.2	4.8	94.2	3.2	95.3	2.1
0	Blend	5	18.1	79.8	19.2	78.1	19.6	76.8	20.6	73.7
5	Synthetic	5	41.8	53.3	47.2	48.3	55.9	45.1	57.3	40.9
5	Natural	5	96.7	2.1	97.1	1.9	97.3	1.5	97.9	1.3
5	Blend	5	49.2	46.1	50.9	44.1	55.3	41.3	58.9	38.7
10	Synthetic	5	57.6	39.8	60.9	35.3	62.5	33.1	64.7	30.4
10	Natural	5	97.8	0	98.3	0	98.9	0	99.2	0
10	Blend	5	73.1	2.3	75.2	20.2	78.9	17.3	80.9	14.4
15	Synthetic	5	98.3	0	98.9	0	99.1	0	99.3	0
15	Natural	5	98.6	0	98.7	0	98.9	0	99.2	0
15	Blend	5	95.1	2.3	96.8	1.8	91.1	1.1	98.2	0.5
20	Synthetic	5	98.5	0	98.9	0	99.1	0	99.3	0
20	Natural	5	99.1	0	99.2	0	99.2	0	99.3	0
20	Blend	5	98.9	0.4	98.7	0.2	98.6	0	98.8	0

Note: P=Penetration percentage, R=Repellency percentage

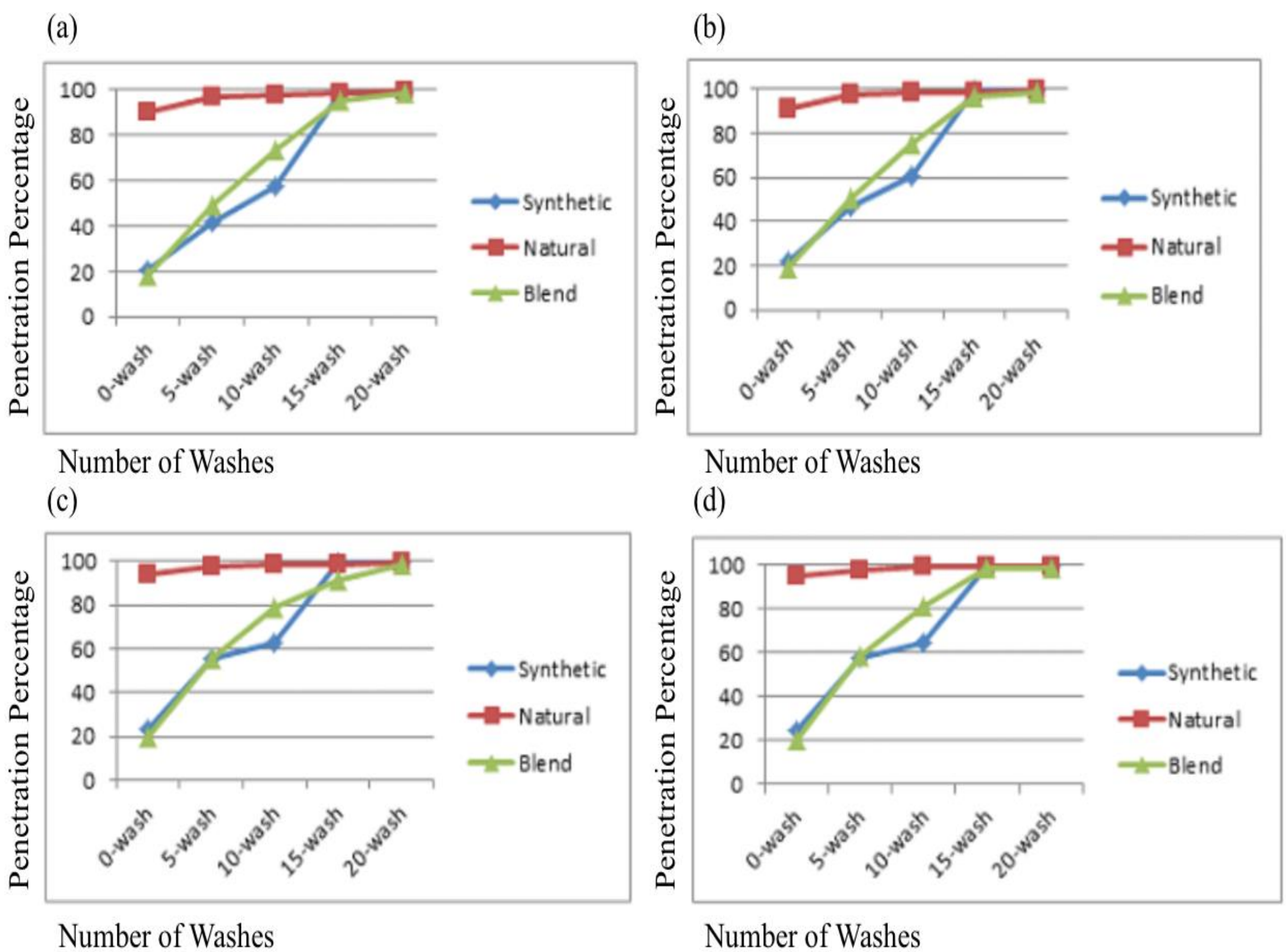

Fig 1: Penetration trend of fabrics against chemicals (a) Sulphuric acid (b) Sodium hydroxide (c) Xylene (d) Butanol.

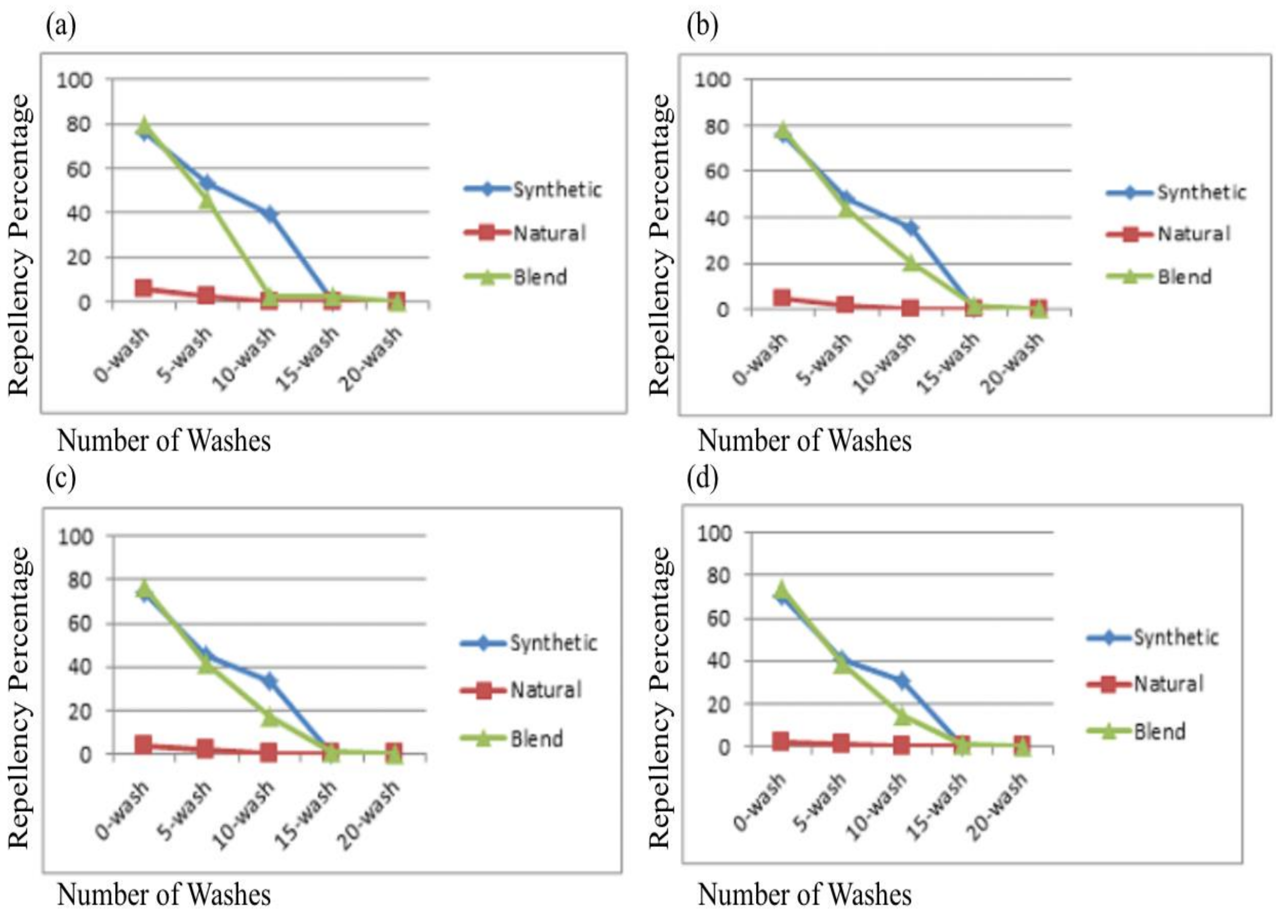

Fig 2: Repellency trend of fabrics against chemicals (a) Sulphuric acid (b) Sodium hydroxide (c) Xylene (d) Butanol

Conclusion: Based on the test results, this study concludes that all samples failed to meet the international safety standards as their performance deteriorated with each laundering cycle. Clothing materials manufactured using synthetic fiber (polyester) performed better against chemicals as compared to natural and blended fabrics.

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