Assessment of Protective Clothing Used by Chemical Industry Workers in Pakistan

Chemical Resistance of Protective Clothing

Mehreen Ijaz
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
mehreenijaz@hotmail.com

Namood-e-Sahar
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
n.sahar6282@gmail.com

Zohra Tariq
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
zohra.tariq@lcwu.edu.pk

Rafia Fatima
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
rafia.fatima@lcwu.edu.pk

Zahra Rasheed
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
zahrarasheed29@gmail.com

Madeeha Tariq
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
madeeha.tariq@lcwu.edu.pk

Hibba Munir Dar
Department of Home Economics
Lahore College for Women University
Lahore, Pakistan
dar_hiba@yahoo.com

Received: 27 August 2022 | Revised: 18 September 2022 | Accepted: 20 September 2022

Abstract-Protective clothing serves as a barrier against many hazards faced by workers in the industry. This study aimed to investigate the performance of locally manufactured clothing used by workers in the chemical industries in Pakistan. The construction parameters were determined using international test procedures for all samples. Then, these were assessed for their chemical resistance behavior after various laundering intervals, following the ISO 6530:2005 test method. After the investigation, it was observed that the collected samples failed to meet the minimum criteria for penetration and repellency through their structure. The samples were unable to repel a minimum of 95% liquid chemical and penetrated it more than 5%, even at zero wash. These conditions worsened with each washing interval. Clothing materials should always be checked for their performance before use.

Keywords-chemical resistance; penetration; repellency; protective clothing; laundering; chemical industry; Pakistan

I. INTRODUCTION

Clothing is considered the second skin for the wearer and protects him against physical, chemical, and environmental hazards. While many advancements have been achieved in the manufacture of protective clothing, there is a lack of a comprehensive and detailed evaluation system in terms of experimentation and regulation [1]. Standard procedures and regulations are very necessary to implement in industries for the welfare of personnel [2]. Chemical protective clothing materials are supposed to be the last defense line for workers dealing with toxic chemicals. Efforts must be made to make the best clothing to provide safety to its wearer. Chemicals vary in their nature from acute to chronic. The industrial working conditions require the wearing of protective clothing to protect the operating staff [3]. The clothing materials should be assessed for their performance before use. Chemical resistance can be evaluated by certain factors such as permeation time, breakthrough time, repellency, retention, penetration index, etc. [4]. Protective clothing is generally classified into various levels according to the protection rate it provides and is made of natural and synthetic fibers or a blend of both [5, 6]. Protective coveralls are generally worn by industry workers [7]. A regulatory body assesses the best protective ensemble for workers based on the toxicity and flammability of the chemicals used in various processes [8]. Accidents caused by chemical exposure in workplaces are horrendous. Workers are often exposed to toxic chemicals without safety measures while working in the industrial sector in Pakistan, resulting in many fatal accidents. Many workers, more than one-third of the respondents in [9], reported high risks associated with chemical exposure. It has been observed that although many toxic substances pose serious risks to their lives, workers expose themselves without wearing an adequate type of protective clothing. Occupational assessment related to the health and safety of workers in Pakistan has yet to receive great importance. Therefore, it is very important to determine

Corresponding author: Mehreen Ijaz

measures and evaluate the performance of the provided protective equipment. The increase in the rate of deaths and injuries of factory employees is caused by the absence of a safety framework or the adoption of poorly administered safety measures [10]. The wages and salaries of most workers in Pakistan are very low. Workers usually do not bother about their health conditions and try hard to do more work regardless of checking the adequate protective measures. A survey carried out by the government of Pakistan showed that approximately 4.1 workers are seriously injured in industrial settings every year [11]. One of the main reasons for injuries is the lack of awareness about the use of protective equipment [12], while 60.9% of the workforce is not familiar with Personal Protective Equipment (PPE) [13].

It should be the responsibility of the employer to provide safety equipment to the workers. An assessment of the risks associated with chemical industries must be made to avoid accidents and injuries. Workers must have a proper protective ensemble to protect themselves from fire and chemical hazards during the handling and storage of hazardous chemicals [14]. As most chemical industries in Pakistan use locally manufactured protective clothing materials for their staff, there is a dire need to evaluate their performance before use. Protective clothing loses its quality with time due to the abrasion caused during work, rubbing during washing, and lack of proper care and cleaning procedures. This study aims to determine the clothing materials used by local chemical industries for their workers, in terms of protection against certain liquid chemicals after various washing intervals.

II. MATERIALS AND METHODS

Chemical industries with head offices located in the Punjab province were approached and locally manufactured protective clothing used by their workers was collected (Figure 1). A total of five categories were identified according to their fiber content.

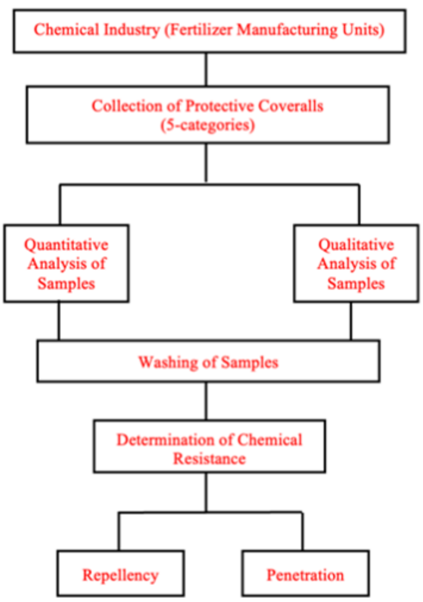

Fig. 1. Flowchart of the research methodology.

The identification of textile fibers is of great importance. There are multiple methods to identify the generic group of fibers, such as burning, microscopic, and chemical tests [15]. The construction specifications of the collected samples were determined through qualitative and quantitative fiber analysis, as shown in Table I.

TABLE I. CONSTRUCTION PARAMETERS OF COLLECTED CLOTHING MATERIALS

Sample code	Fiber content	Yarn count: warp×weft (thread count)	Fabric mass (gsm)	Linear density (warp × weft)
AB-1	Cotton 40% Polyester 60%	113×95 (208)	150	17.21×15.43
AB-2	Cotton 70% Polyester 30%	95×75 (170)	138	16.34×16.34
AB-3	Cotton 95% Rayon 5%	105×68 (173)	162	17.29×18.91
AB-4	Cotton 98% Polyester 2%	99×76 (175)	125	18.32×15.63
AB-5	Cotton 50% Polyester 50%	110×85 (195)	121	15.34×18.45

Qualitative analysis was performed using the AATCC test method [16] to find the generic group of fibers. The samples were dipped in distilled hot water to remove impurities and were then treated with a 0.5% solution of sodium hydroxide to separate the vegetable matter. After that, the samples were washed out and dried. The dyed samples were stripped with 0.5% sodium hydrosulfite at 50°C for half an hour. Afterward, a visual examination was performed of physical parameters such as color, yarn length, fineness, number of neps, thickness, and uniformity. Fibers were identified at pre-burning, during burning, and post-burning stages through a burning test. Microscopic evaluation was also performed with longitudinal and cross-sectional views of the samples. A quantitative analysis was followed using the chemical test adopting the instructions given in the AATCC test procedure [17]. The samples from each group were taken and treated with the relative reagent to measure the solubility ratio given in the standard. The yarn count in both the warp and weft directions was determined using the standard test procedure [18]. The number of yarns in the test area of one inch was counted with the help of a magnifying counting glass. The thread count was calculated by adding the number of warp and weft yarns. The fabric mass was determined by following the standard procedure of [19]. The samples were measured in a weighing balance and the mass per unit area of m^2 was recorded with an accuracy level of ±0.1%. The linear density in both directions was also identified [20]. The length and mass of the yarns were determined with the respective scales and calculations were carried out to measure the linear density.

The performance behavior of protective clothing must be evaluated after various washing intervals. Standard laundering procedures must be followed to verify the efficiency and adequacy of textile materials up to a specific number of intervals [21]. After identifying the construction specifications of the samples, they were laundered through the American Association of Textile Chemists and Colorists (AATCC) Monograph [22] in a front load washing machine under the agitation speed of 45±10rpm. The temperature was set to 54°C for 11±1 minutes. An approximate 0.1g/liter standard detergent was added in each wash cycle. The samples were spun at 1300rpm for about12 minutes. The tumble drying was made at 68°C for one and a half hours.

A total of 15 laundering cycles were applied to the samples from each category. After every 5 cycles, they were labeled and processed for further testing. All test samples were kept at a temperature of 21°C and 65% relative humidity for one day [23]. The samples were assessed for their resistance against 4 liquid chemicals, i.e. sulphuric acid, sodium hydroxide, xylene, and butanol, according to the procedure defined by ISO 6530:2005 [24], through their ratios of penetration and repellency. This method helps determining the rate of penetration and repellency against these liquid chemicals [25]. The samples from each group were cut into 14×9 inch pieces and were taken as an upper layer. An absorbent sheet with a plastic back of the same dimensions was also acquired and weighed separately. Their distance was approximately 1 inch and they were placed on a collector layer. This test assemblage was tilted at 45°. Ten milliliters of each chemical were poured off through a nozzle from the test fabric and were collected in a beaker placed beneath it. After a minute, both layers were separated and weighed again. The chemical retained by the collector layer was considered for the penetration rate. The chemical in the beaker was recorded as the repellency rate. At least one of the chemicals should repel 95% and penetrate less than 5% of the samples. The rate of penetration was measured as:

$$P = \frac{A \times 100}{B} \quad (1)$$

where A is the chemical retained by the absorbent sheet and B is the chemical retained by the test specimen. The rate of repellency was calculated as:

$$R = C \times \frac{100}{B} \quad (2)$$

where C is the chemical collected in a beaker and B is the chemical retained by the test specimen.

III. RESULTS AND DISCUSSION

The tested clothing materials did not pass the minimum performance criteria for protecting against liquid chemicals. The samples did not repel 95% of any chemical, even at the initial washing cycles. Moreover, more than 5% of each chemical penetrated them even at zero washes. The condition worsened with each washing interval. One of the main reasons was the increase in the porosity of the fibers due to the laundering cycles, as they opened their structure and allowed the chemical to pass through more easily. The difference between samples was due to the variation in fiber content. It is always necessary to study the chemical resistance of protective clothing worn by workers for protection. Laundering thins the fibers due to the constant rubbing in the washing machine and weakens them, letting the liquid pass through them [26]. The kind of polymer plays an important role in determining the chemical behavior of fabrics [27]. It was found that specimen AB-1 performed well, followed by AB-5 and AB-2, due to the presence of polyester fibers which helped repel the chemicals. It was also found that the fabrics were made in a single layer with low mass rates, which also caused them to allow the penetration of more chemicals and repel less [28]. The increase in mass and the number of layers increases the time it takes for any chemical to penetrate the structure [29, 30]. The lamination and coating applied on the surface of fabrics also makes them strong and durable against the penetration of liquids. It was observed that the tested samples were laminated with weak finishing treatments that leaked the chemicals in the very initial washing cycles. This treatment was removed at the last interval and all liquid chemicals permeated through the fabric structure, as seen in Table II.

TABLE II. RATE OF PENETRATION AND REPELLENCY OF TESTED SPECIMENS

Laundering cycle	Sample code	Sulphuric acid		Sodium hydroxide		Xylene		Butanol	
		P	***R***	***P***	***R***	***P***	***R***	***P***	***R***
0	AB-1	21.7	78.7	29.6	70.8	34.8	65.7	23.8	75.4
0	AB-2	38.5	61.5	48.6	49.8	64.2	34.8	49.8	45.8
0	AB-3	51.2	45.7	68.6	32.4	79.6	22.7	57.6	39.6
0	AB-4	50.9	41.1	66.2	32.9	78.5	20.7	73.9	25.1
0	AB-5	29.7	69.6	44.8	54.9	48.2	49.2	59.1	41.4
5	AB-1	39.7	61.5	49.7	51.4	49.3	48.1	48.9	49.7
5	AB-2	42.3	56.8	55.7	41.9	49.7	49.3	48.6	47.3
5	AB-3	50.8	38.3	73.6	27.9	72.3	24.2	78.5	19.6
5	AB-4	62.6	35.4	75.8	24.8	86.6	13.2	68.3	29.6
5	AB-5	48.6	51.7	55.8	43.6	59.8	41.8	58.2	41.8
10	AB-1	41.2	61.9	49.8	49.7	63.5	33.6	41.2	58.6
10	AB-2	59.8	41.8	67.8	32.1	78.1	21.5	42.8	37.5
10	AB-3	71.2	28.4	82.5	14.9	88.5	17.3	81.1	18.5
10	AB-4	68.9	29.2	80.5	19.5	88.5	11.2	83.5	15.8
10	AB-5	68.6	31.4	65.9	31.7	83.1	15.6	82.2	18.5
15	AB-1	79.7	22.5	69.2	29.5	76.3	22.4	82.9	17.4
15	AB-2	77.8	20.9	81.4	17.2	90.9	7.5	88.9	11.4
15	AB-3	80.4	18.7	88.5	11.6	92.5	7.3	88.6	10.2
15	AB-4	88.7	10.5	90.7	9.5	94.2	5.4	91.4	8.4
15	AB-5	76.7	22.7	85.6	13.5	89.3	9.9	89.1	10.8

Note: P=Penetration %age, R=Repellency %age

The penetration and repellency of the tested specimens were directly proportional to the laundering cycles. Analysis of Variance (ANOVA) was applied to measure the difference between specimens after washing intervals of 0, 5, 10, and 15 cycles. The p-values, 0.00 and 0.001, show that specimens deteriorate in their performance with each washing interval for penetration and repellency respectively, as seen in Table III.

TABLE III. STATISTIC ANALYSIS AT VARIOUS WASHING INTERVALS

Chemical resistance	Washing interval	Mean square	F	p-value
Penetration	Linear	17965.23	46.76	0.00
Repellency	Linear	15674.52	38.91	0.01

IV. CONCLUSION

This study concluded that the locally manufactured protective clothing does not provide complete protection against liquid hazards. The variation in the results was due to the variation in the construction parameters of the collected samples. The performance of the materials worsened with the increasing number of washing cycles. This study can help textile manufacturers to make amendments to their construction parameters and techniques in order to provide better protection against chemical hazards. Every industry has its performance requirements.

V. FUTURE WORK AND LIMITATIONS

This study was limited to the chemical industries, while follow-up studies should evaluate the performance of clothing used by the textile sector and medical or agricultural personnel. Follow-up studies should also investigate other items of protective clothing, such as gloves and masks, as this study was limited only to protective coveralls. Moreover, future studies should examine the risks of fire hazards. Furthermore, future studies should also investigate the perceptions and experiences of employees and employers to point out factors that will boost the establishment of safety frameworks in industries.

REFERENCES

[1] N. Karim *et al.*, "Sustainable Personal Protective Clothing for Healthcare Applications: A Review," *ACS Nano*, vol. 14, no. 10, pp. 12313–12340, Oct. 2020, https://doi.org/10.1021/acsnano.0c05537.

[2] Z. Khan, Y. B. Yusof, N. H. B. Abass, M. B. I. Ahmed, and Q. B. Jamali, "Recommendations for the Implementation of ISO 9001:2015 in the Manufacturing Industry of Pakistan," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7177–7180, Jun. 2021, https://doi.org/10.48084/etasr.4075.

[3] E. Khalil, "A Technical Overview on Protective Clothing against Chemical Hazards," *AASCIT Journal of Chemistry*, vol. 2, no. 3, pp. 67–76, Jun. 2015.

[4] M. A. Uddin, S. Afroj, T. Hasan, C. Carr, K. S. Novoselov, and N. Karim, "Environmental Impacts of Personal Protective Clothing Used to Combat COVID- 19," *Advanced Sustainable Systems*, vol. 6, no. 1, 2022, Art. no. 2100176, https://doi.org/10.1002/adsu.202100176.

[5] A. H. Memon, M. H. Peerzada, K. Muhammad, S. A. Memon, S. A. Mangi, and G. Mujtaba, "Recent Eco-Friendly Developments in Personal Protective Clothing Materials for Reducing Plastic Pollution: A Review," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 4012–4018, Apr. 2019, https://doi.org/10.48084/etasr.2674.

[6] US EPA, "Personal Protective Equipment," *Personal Protective Equipment*, 2020. https://www.epa.gov/emergency-response/personal-protective-equipment.

[7] F. Siddiqui, M. A. Akhund, A. H. Memon, A. R. Khoso, and H. U. Imad, "Health and Safety Issues of Industry Workmen," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3184–3188, Aug. 2018, https://doi.org/10.48084/etasr.2138.

[8] K. Niinimäki, G. Peters, H. Dahlbo, P. Perry, T. Rissanen, and A. Gwilt, "The environmental price of fast fashion," *Nature Reviews Earth & Environment*, vol. 1, no. 4, pp. 189–200, Apr. 2020, https://doi.org/10.1038/s43017-020-0039-9.

[9] M. Khan and C. A. Damalas, "Occupational exposure to pesticides and resultant health problems among cotton farmers of Punjab, Pakistan," *International Journal of Environmental Health Research*, vol. 25, no. 5, pp. 508–521, Sep. 2015, https://doi.org/10.1080/09603123.2014.980781.

[10] F. Lamm, C. Massey, and M. Perry, "Is There a Link between Workplace Health and Safety and Firm Performance and Productivity?," *New Zealand Journal of Employment Relations*, vol. 32, no. 1, pp. 75–90, https://doi.org/10.3316/informit.135846714466567.

[11] Pakistan Bureau of Statistics, "Labour Force Survey 2012-13 (Annual Report)," 2013.

[12] W. A. Khan, T. Mustaq, and A. Tabassum, "Occupation Health, Safety and Risk Analysis," *International Journal of Science, Environment and Technology*, vol. 3, no. 4, pp. 1336–1346, Aug. 2014.

[13] A. R. Khoso, M. A. Akhund, A. H. Memon, F. Siddiqui, and S. H. Khahro, "Health and Safety of Hyderabad Industries' Labor. Causes and Awareness," *Engineering, Technology & Applied Science Research*, vol. 7, no. 6, pp. 2334–2339, Dec. 2017, https://doi.org/10.48084/etasr.1626.

[14] Najaf Shah *et al.*, "Assessment of the Workplace Conditions and Health and Safety Situation in Chemical and Textile Industries of Pakistan," *Science Journal of Public Health*, vol. 3, no. 6, pp. 862–869, Dec. 2015, https://doi.org/10.11648/j.sjph.20150306.20.

[15] M. M. Houck, *Identification of Textile Fibers*. Amsterdam, Netherlands: Elsevier Science, 2009.

[16] "Test Method for Fiber Analysis: Qualitative," American Association of Textile Chemists and Colorists, Research Triangle Park, NC, US, Standard AATCC TM20-2021, 2021.

[17] "Test Method for Fiber Analysis: Quantitative," American Association of Textile Chemists and Colorists, Research Triangle Park, NC, US, Standard AATCC TM20A-2021, 2021.

[18] "Standard Test Method for End (Warp) and Pick (Filling) Count of Woven Fabrics," ASTM International, West Conshohocken, PA, US, Standard ASTM D3775-17e1, 2018.

[19] "Standard Test Methods for Mass Per Unit Area (Weight) of Fabric," ASTM International, West Conshohocken, PA, US, Standard ASTM D3776/D3776M-20, 2020.

[20] "Standard Test Method for Yarn Number Based on Short-Length Specimens," ASTM International, West Conshohocken, PA, US, Standard ASTM D1059-17, 2019.

[21] M. Ijaz, S. Kalsoom, and N. A. Akthar, "Abrasion Resistance of Materials Used for Chemical Protective Clothing at Various Washing Intervals," *Scientific International Journal (Lahore)*, vol. 28, no. 1, pp. 411–414, 2016.

[22] "Standardization of Home Laundry Test Conditions," *AATCC Technical Manual 2017*, vol. M6-2016, pp. 457–460, 2016.

[23] "Standard Practice for Conditioning and Testing Textiles," ASTM International, West Conshohocken, PA, US, Standard ASTM D1776/D1776M-20, 2020.

[24] "ISO 6530:2005 - Protective clothing — Protection against liquid chemicals — Test method for resistance of materials to penetration by liquids," International Organization for Standardization, Geneva, Switzerland, Standard ISO 6530:2005, 2005.

[25] P. Otřísal, S. Florus, and R. Karkalić, "Resistance of Barrier Materials Against Toxic Compounds Permeation and Its Evaluation in Accordance with New European Norms," *International conference - The Knowledge-based Organization*, vol. 23, pp. 224–233, Jun. 2017, https://doi.org/10.1515/kbo-2017-0182.

[26] S. Krzemińska and W. M. Rzymski, "Barrierity of Hydrogenated Butadiene-Acrylonitrile Rubber and Butyl Rubber After Exposure to Organic Solvents," *International Journal of Occupational Safety and*

Ergonomics, vol. 17, no. 1, pp. 41–47, Jan. 2011, https://doi.org/10.1080/10803548.2011.11076869.

[27] U. Sata, E. Wilusz, S. Mlynarek, G. Coimbatore, R. Kendall, and S. S. Ramkumar, "Development of Cotton Nonwoven Composite Fabric for Toxic Chemical Decontamination and Characterization of its Adsorption Capabilities," *Journal of Engineered Fibers and Fabrics*, vol. 8, no. 1, Mar. 2013, Art. no. 155892501300800130, https://doi.org/10.1177/155892501300800112.

[28] G. E. Ibrahim, A. F. Abdel-motaleb, and E. R. Mahmoud, "Achieving Optimum Scientific Standards for Producing Fabrics Suitable for Protecting Against Hazardous Chemical Liquids," *Life Science Journal*, vol. 9, no. 1, pp. 342–353, 2012.

[29] S. Krzeminskaa and W. M. Rzymski, "Thermodynamic Affinity of Elastomer-Solvent System and Barrier Properties of Elastomer Materials.," *Acta Physica Polonica*, vol. 124, no. 1, pp. 146–150, Jul. 2013.

[30] International Labour Organization, "Encyclopaedia of Occupational Health and Safety," 2012. https://www.ilo.org/safework/info/publications/WCMS_113329/lang--en/index.htm.