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Balancing aesthetics, and functionality with comfort: Compliance-friendly protective clothing

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Abstract

History is created when technology and innovations come together. Blending this with aesthetics opens a new plethora of opportunities. Protective clothing (PC) combines technology and innovations. It is part of technical textiles, which comprise those textiles-based products, primarily used for their performance rather than the aesthetic value. PC is designed to shield or isolate individuals during occupational operations from physical, chemical, and biological hazards. This paper aims at designing compliance-friendly protective clothing for petrochemical, agrochemical, fluorochemical industries, and Original Equipment Manufacturers (OEMs). Though meant for safety, the chemical industries & OEMs see a major lack of compliance. The authors start a discussion that workers are more likely to wear PC if it meets their aesthetic expectations along with maintaining comfort at work. There is potential to advance what we wear, and how it's designed, manufactured, and marketed to the world. Fashion is moving beyond fanciful borders towards a new wave of innovators aiming to impact fashion on an everyday level. The PC market saw initial developments in the finish of fabrics, after which comfort with functionality came along. This needs to evolve into blending smart textiles, comfort, and style statement. Presently industrial workers have no other choice but to wear current safety wear under the pretext of safety compliance. The researchers through this paper look to provide new design solutions for industrial workers, which blend their safety with fashion. The target market includes select OEMs and chemical industry workers. The research methodology will include a detailed survey by convenient sampling for the assessment of clothing needs. The key is to balance function (protection) and form (style, comfort, and wearability) within the scope of a realistic hazard assessment and risk analysis.

Keywords: Safety professional, personal protective clothing, smart textiles, fashion - safety & comfort

Introduction

Clothing, one of the basic needs of human beings focuses on protection and modesty. Eventually, aesthetics took over the need for protection. Currently, there is again a shift to have protection as the functionality-giving rise to the protective clothing segment. Protective clothing (PC) is part of Personal Protective Equipment (PPE), which is designed with the sole purpose of protecting the wearer from infection or injury. PC includes clothing and equipment worn over or in place of regular work clothing to protect the workers from toxic gases, harmful chemicals, heat exposure, etc. It may not reduce the harmful effect of chemicals but it sets up a barrier against chemicals, enhancing the safety of the people working under hazardous conditions. Designing protective clothing, one needs to consider many factors that influence its effectiveness. Each potential risk has different problem areas and needs specific solutions in form of PC. This research paper concentrates on designing PC segments for petrochemical, agrochemical, OEMs, and various other chemical industries.

There is a distinct lack of safety culture in India, despite so many chemical industries the concept of protective clothing is still in the infancy stage. The solution to this problem lies in educating the workers about the safe handling of chemicals. In the majority of the units/industries workers are wearing work clothes but they hardly provide any protection against harmful chemicals or the Protective suit available is uncomfortable. Workers are provided with accessories like goggles, gum boots, masks helmets, and gloves, which hardly they are using because of discomfort in wearing them in hot and humid climates (Mona Suri, 2002) ^[20].

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Designing protective clothing

Clothing defines how people perceive themselves and is a necessary part of their everyday lives. It has the potential for a multidisciplinary functional approach while promoting a feeling of well-being. Good aesthetic and technical design, driven by meaningful end-user research, can help exploit niche markets where form and function work in harmony in the research and development of comfortable and attractive products that can assist us in many aspects of our daily lives. (McCann).

Protective clothing primarily acts as a physical barrier between the skin and chemicals. PC to be an efficient barrier should cover all the areas that are prone to chemicals and be made of fabric that can prevent penetration. The penetration performance of a fabric depends on various parameters. Fiber content affects the chemical penetration. Cotton has been found to provide greater protection than polyester-cotton or 100% polyester (Leonas, 1991) ^[15]. Though pure cotton and polyester-cotton blends offer more protection, none of them provides complete protection. Spun bonded olefin fabrics (Tyvek®) and Polytetra fluoroethylene laminates (Gortex®) have been specially made to provide dermal protection from harmful chemicals but their cost and availability are the limiting factors (Branson & Sweeney, 1991) ^[5]. Non-woven fabrics in general appear to perform better than most woven or knitted fabrics; however, close weave fabrics like heavy-weight twill fabrics also perform considerably well (Easter & DeJonge, 1986) ^[6].

The surface properties of fabric can be altered by treating it with a topical covering in the form of a renewable or durable

finish. C₆ chemistry perfluorochemicals (PFC) are the only chemicals capable of repelling water, oil & other liquids that cause stains. Fabrics finished with PFCs have nonstick properties. This family of chemicals is now available and is reasonably priced. C₆-C₈ fluorinated water repellents are widely used on textile products due to their outstanding ability to protect against water, oil, and soil. For the sake of safety, there is a shift towards fluorinated water repellents are 'C₆' or 'C₄' indicating the number of carbons in the perfluorochemical chains.

According to the paper by J.Gerask & M.Marcic on the Complex Design Concept for Functional Protective Clothing, Designing protective clothing as an integral part of personal protective equipment (PPE) is an extremely complex task. PC must be designed and manufactured by foreseeing those conditions of use for which it is intended so that the user can perform the risk-related activities normally whilst still enjoying, at the same time, appropriate protection at the highest possible level.

The technical developments are used in enhancing the functionalities of protective clothing systems - by providing intelligent functions to this type of clothing. Functional PC provides special functionality for the wearer, such as assistance when monitoring and evaluating those potential hazards encountered by the user, such that conventional protective clothing could not. Functional protective clothing with intelligent characteristics is also considered to be an object of interdisciplinary research, covering different disciplines.

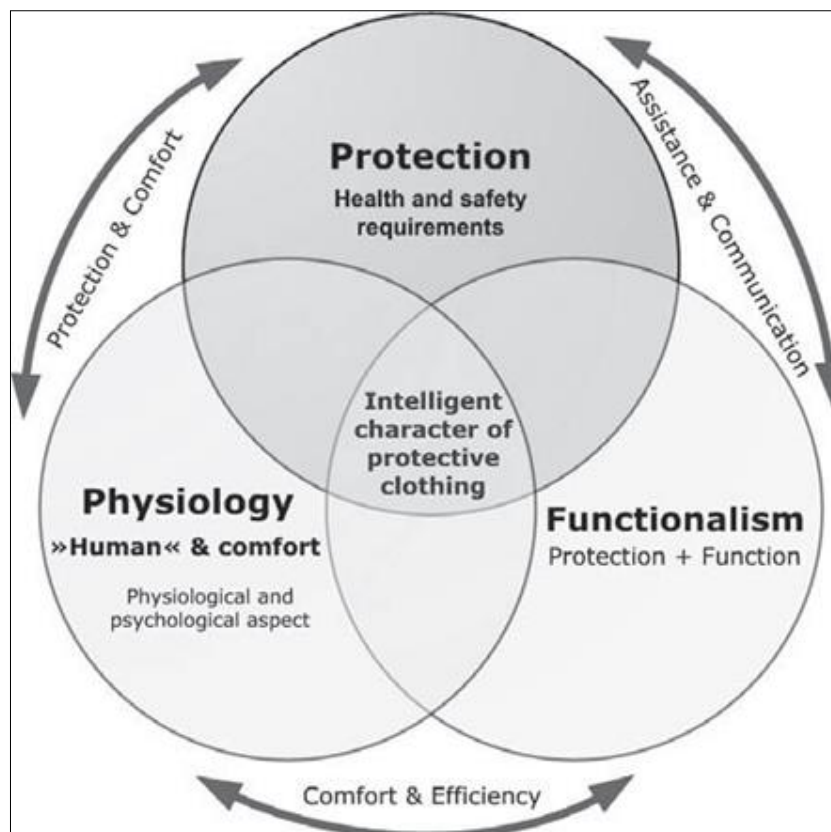


Plate 1: Multidisciplinary approach to functional protective clothing (Source: J. GERŠAK, M. MARČIČ: The complex design concept for functional protective clothing, *Tekstil 62* (1-2) 38-44 (2013) ^[16])

The multi-disciplinary nature of functional protective clothing with intelligent characteristics necessitates the integration of protection research, material science, clothing engineering, comfort, and functionality, whilst including the objectives of the environment and communication, as illustrated in Plate I

the multidisciplinary approach to functional Protective Clothing Protective clothing should be practical, functional, and comfortable. It should also be acceptable to the individuals who will wear it (Henry, 1980) ^[5]. Protective clothing should be similar in design or style to the regularly

worn work clothing. Thus problems associated with chemical penetration, garment comfort, aesthetic styling, and sizing should be solved at this stage. The key requirement of design development for PC involves functionality and comfort as the only focus. But at the same time, the authors based on interviewing workers in chemical process-based industries propose that for PC to be acceptable it needs to have a multidisciplinary approach to strike a balance between providing safety and protection, functionality, human comfort, and psychosocial aspect. Along with these factors, PC should be economical so that most small-scale industries can afford them.

The design concept for functional protective clothing, where design criteria for functional protective clothing must be unequivocal and specified; for example, protection from chemicals is achieved by blocking their penetration and permeation through the fabrics of the clothing. This is an effective method for providing sufficient protection; however, total blockage of the penetration and permeation also affects the transport of any heat and moisture generated by the wearer of the protective clothing and results in possible heat stress. It witnesses the complexity of designing protective clothing and asks for even higher requirements when designing this type of protective clothing, both from the point of view of protection and comfort and from that of functionality. Thus, the current status of PC shows clearly a need for developing PC that is functional, comfortable, and also has aesthetics. The same was reflected in the interviews with the workers, which will be discussed later in the paper.

Objective of the study

To identify the Petrochemical, Agrochemical, OEMs, and various other chemicals industries; and to assess the clothing needs of the workers in these Industries

1. To design Protective Clothing of level D as per Occupational Safety and Health Standards (OSHA), a basic work uniform affording minimal protection and only for nuisance contamination, using the available smart textiles that are suitable for the right hazards.
2. To design a PC that breaks the usual practice of being only functional and instead strikes a balance between functionality, comfort, and aesthetics of PC ensuring utmost safety.

Methodology

The sampling frame is based on the Interviews conducted with 35 industries in the Western and Northern regions of

India. For this study, 450 workers and 150 safety professionals, Engineers, and scientists have been selected randomly from 35 different process-based Industries and OEMs (Original Equipment manufacturers).

A study was conducted in a phased manner. The industries were identified to conduct the survey. Based on their requirement the right Protective Textiles were identified and the suitable PC based on the protection requirement.

The authors propose a selection of smart textiles based on the hazard they are prone for various body areas like the entire body – encapsulated suit; torso and arms – coveralls; torso, head, arms, and legs – hooded coveralls; head – booties; etc.

Textile Industry contributes majorly to increasing the safety of workers on the field, through innovation and alliances. Once the need for Protective Clothing is decided the safety professional sees to it that the frontline worker uses and maintains it correctly. Proper selection, training, and use of PC are essential. An Interview was conducted with the workers and safety professionals to understand how the workers do their job, how they use their personal protective equipment, and the level of exposure to multiple hazards as part of their everyday job work. As a result, a direct correlation between the hazard and the protective material has been proposed and this is viewed as the full selection.

Selection criteria of requisite features of PC:

- It should adequately protect against severity, nature and type of hazard.
- It should be of minimum weight and should give minimum discomfort with protective efficiency.
- It should provide ease of movement and comfort for carrying out required job
- It should be durable and aesthetically appealing.
- It should not cause any hazard through its material, design, defect, use, or failure.
- It should comply to Indian Standards and necessary tests.
- It should be easy to maintain, care for and repair.

An effort needs to be made to achieve the maximum of the above.

Various chemical resistant materials are available in the market such as Teflon a fluorinated - ethylene propylene material for face shields. Viton-Fluorinated material developed by Du Pont co. for protective gloves.

There is a variety of Personal Protective clothing available for specific work situations. However, the selection of the most appropriate form of protection is very complex, as safety mobility and dexterity, comfort and cost must be balanced.

Table 1: Selection of material for the construction of Protective Clothing as per the nature of the hazard.

Material	Kind of Hazard	Application	End Use Industry
Conductive rubber	Explosive substance		Petrochemical Industry, Refineries, Oil and Gas Industry
Chrome leather	hot substance, flying particles, sharp edge, abrasion, sparks	Mechanical	Boiler Manufacturers, Fabricators, Vessels manufacturers, Reactors Manufacturers
Canvas	Flying particles, sharp edge, abrasion, machinery		OEM's
Kermel Denim	Heat, hot substance, sparks	Thermal Mechanical	Boiler Manufacturers, Fabricators, Vessels manufacturers, Reactors Manufacturers
Tyvek	Hot substance	Petrochemical & Chemical industrial cleaning and maintenance, and land clean-up	Petrochemical & Chemical Industry
Acid proof Fabric (Tychem, Microchem)	Acid and alkali	chemical oil handling, land decontamination, production plant decommissioning, industrial cleaning and maintenance, tank and oil tanker cleaning, spill clean-up and accident	oil and gas industry, petrochemical Industry

		intervention, the gas supply sector, typical chemical industry applications	
Reflective fabric	Hot liquid	Visibility	Typical Chemical Industry, Petrochemical Industry
Flame-resistant fibers (Flame retardant finished fabrics - Proban, Pyrovatex, Nomex, Kevlar, Ultra Basofil (melamine fiber)	Heat, hot substance, sparks, chemicals, flying particles, machinery	Thermal Chemical UV resistance	Oil and Gas Industry, Hazardous Chemicals Industry, Petrochemicals, Refineries, Fertilizers
Woolen fabric, worsted fabric	Hazardous liquids (Sulphuric acid, hydrochloric acid, nitric acid), acid resistant	Chemical	Chemical Industry, Petrochemical Industry
Cotton canvas	sharp edge, abrasion	Mechanical	OEMs, Fabricators
Goretex, Tetratex, Porelle, Proline, Vapro, sympatex, Action, Neo Guard	Waterproof permeable, moisture barrier		Water Treatment Plants, Effluent treatment Plants, distillery and Brewery Plants

The PC will be first stitched based on the above-mentioned identified fabrics. It would then be processed with washes such as mechanical/chemical wash as per the design requirement. The washed PC will then be treated with suitable protective finishes to enhance the shielding against possible hazards and to ensure the safety of the wearer. The washing is

an aesthetic finish given to the denim fabric/Protective textile to enhance the appeal and provide strength. After the identification of fabrics, the authors proposed developing a Design framework for the conceptualization of Protective Clothing.

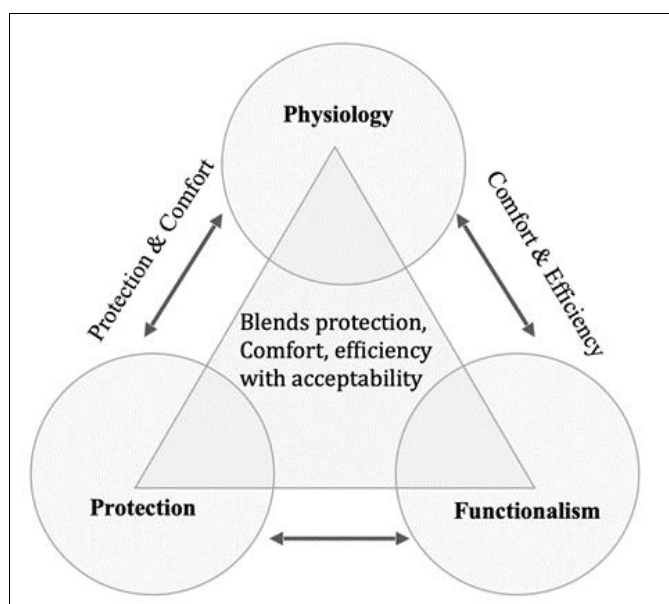


Plate II: Suggested design framework for functional protective clothing

The authors based on their research went across to modify J. Kersak and M. Marcic’s design framework to understand designing PC and its acceptability. Permissions and consent were taken from the industries to ensure no disturbance and harm occurred during the procedures for evaluations and voluntary participation of the participants.

Results and Discussion

Design of Protective Clothing for the selected industries has a vast scope of work and a complicated task that depends on several theories of heat losses, thermal insulation, chemical exposure, fabrication, etc. The new design area of smart textiles and wearable PPE demands the merging of methodologies across disparate disciplines to inform the application of wearable technologies in smart clothes that have the potential to enhance the quality of life of the target wearer.

The functional design process attempts to externalize the creative thinking of traditional fashion designers by

strategizing the design process. A major advantage of bringing design thinking into the open is that other people, such as users can see what is going on, contribute information, & provide insight to solutions that may be outside the designer's knowledge and experience. The end product of the functional design approach is not only met especially the clothing needs of the users such as providing a barrier to toxic chemicals but also looks at the users' environment including the near as well as the external environment. For example, the heat stress on the user and the climatic conditions under which the user will be working. This approach attempts to accommodate these environments. The solution to the design problem incorporates the knowledge of fashion and human needs into functional design. Overall, a functional PC is designed to meet the physical, social, psychological, and aesthetic needs of the potential users.

Aesthetic design is for appearance only. In the functional design process, it is critical that the aesthetic design not affect the fit or performance of the garment. It must agree with both

the functional and structural designs. This means that functional design or each aspect of a design such as a zipper may also be decorative, but if the design deals exclusively with human protection and safety, the function of a zipper must be eased by donning and doffing the garment with appropriately sealed seams or cover flaps. On the other hand, if the aesthetic needs of the end user have not been met, the garment will not satisfy the needs of the end user. A different perspective is been provided towards the design approach.

Primary qualitative research methods were employed, in semi-structured interviews with safety professionals and workers, to verify and elaborate designs and any further issues uncovered. With the interview conducted with the safety professionals & workers, the response is to conduct training to create awareness about the right way of the use Protective clothing and awareness of the hazards of the respective process industry.

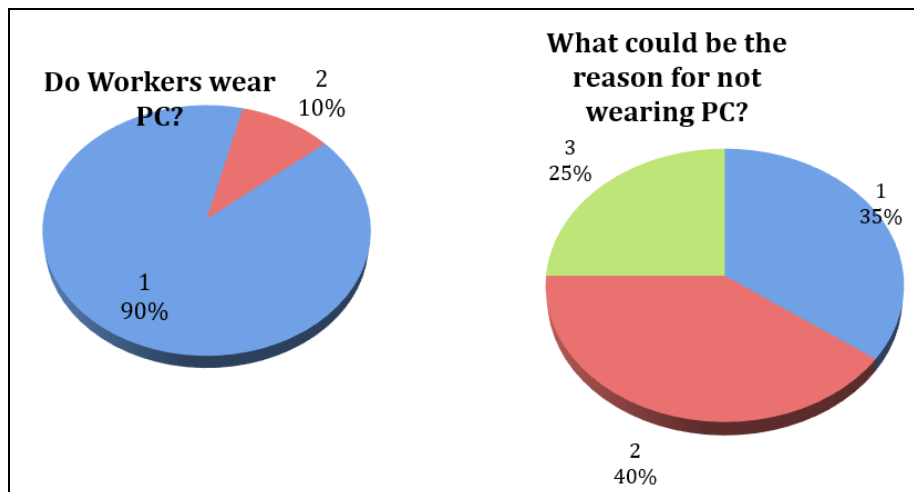


Plate III: Responses for the survey stating the compliance of PC and reason for non compliance of wearing PC

The clothing designed should always be ergonomically fit. With Safety, comfort, and fit, style plays an important role. No discrimination is to be done among workers and higher safety officials for the uniform is designed to be 100% acceptability. The protective clothing should be similar to the uniforms worn by the workers to ensure greater acceptability by them.

In Design, the fit is considered successful in PC when the needs of the wearer are achieved along with the required functionality of the garments. This is a delicate balance to achieve. Depending on the requirements of the situation, protective clothing could be a simple layer of fabric or a very complex and multi-layered system. The choice of materials, design parameters, fiber, and fabric properties all play critical roles in the designing of protective clothing. The entire blueprint response is targeting risk, working safer, working smarter, and working together.

The exhaustive data collected by interviewing the workers, supervisors, and engineers of process-based industries were analyzed. The analysis suggested that though most of the workers wore PC, they were not comfortable with the protective clothing. The major reasons for not wanting to wear them were discomfort due to feeling too hot and that they felt the movement gets restricted. PC which is smart and with design aesthetics will help find a motivation for the workers to wear them. They all agreed that PC is essential for process-based industries and also need training for knowing how to wear PC in the right manner.

The authors also interacted with senior officers in leading chemical industries dealing with toxic chemicals where the use of PPE is compulsory. However, there exists a problem of

non-compliance by not using PPEs even when a maintenance job is carried out handling toxic chemicals. Many times the personnel get away by sheer luck. When enquired the usual answer is that these are uncomfortable or boring. There is a need for comfort and fit that plays a part in durability, since garments that fit better wear better. The focus is on three areas: continuing & improving the high level of protection; increasing movement while bringing the garment closer to the body and improving the look of the PC to encourage wearing compliance. Further designing them fashionable; would make them want to wear them. This would greatly enhance compliance and prevent hazards.

Design solutions for protective clothing

The key elements followed while designing were:

- Designing using technical textiles like Kermel Fabric helps create a synergy between aesthetics, safety, and comfort. Using reflective tapes as a design element as well as to provide maximum coverage for complete visibility.
- Quotes and logos to encourage safety at the workplace.
- Use of mandarin collar, ribbed collars, and hems, cuffs to ensure better resistance to the penetration of chemicals.
- Use of lightweight stretch fabric.
- Multi-panel seam designs, raglan sleeves
- Flat seam constructions
- Tag fewer labels & Garments that fit better
- Increase in shoulder size and lengthening of zippers ad plackets for ease of getting in and out of the suits.
- The areas prone to more wear and tear and stress like waistbands to be reinforced

Based on the research, analysis and feedback, the following designs were developed by the authors

DESIGN SHEET NO 01

Target Client: Workers working at OEMs and Process Industries
Problem Faced : Chemical Exposure and fluctuating workspace climate



- Reflective fabric tape on collar.
- Reflective fabric tape as a collar stand.
- Reflective fabric as a patch.
- Wocky Tocky phone pocket.
- Reflective fabric tape
- concealed placket with zip.
- Reflective fabric tape
- Pocket with flaps
- lopes for hanging materials



- Reflective fabric tape on collar.
- Reflective fabric as a patch.
- Reflective fabric tape color gray
- Reflective fabric tape color gray
- Reflective fabric tape
- Reflective fabric tape color gray.
- Ribbed hem finished.

# 7682 C


# 715 C

# 420 C


Plate IV: Design sheet 1 comprising of a shirt design proposed for the workers

DESIGN SHEET NO 02


Target Client: Workers working at OEMs and Process Industries
Problem Faced : Chemical Exposure and fluctuating workspace climate




- Air ventilator flaps
- Reflective fabric piping.
- Reflective fabric tape
- Reflective fabric piping.
- Ribbed hem finished



- Reflective fabric tape
- Reflective fabric piping.
- Reflective fabric tape. color gray
- Ribbed hem finished

# 7682 C

# 715 C

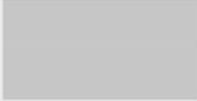
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Plate V: Design sheet 2 comprising of a shirt design proposed for the worker

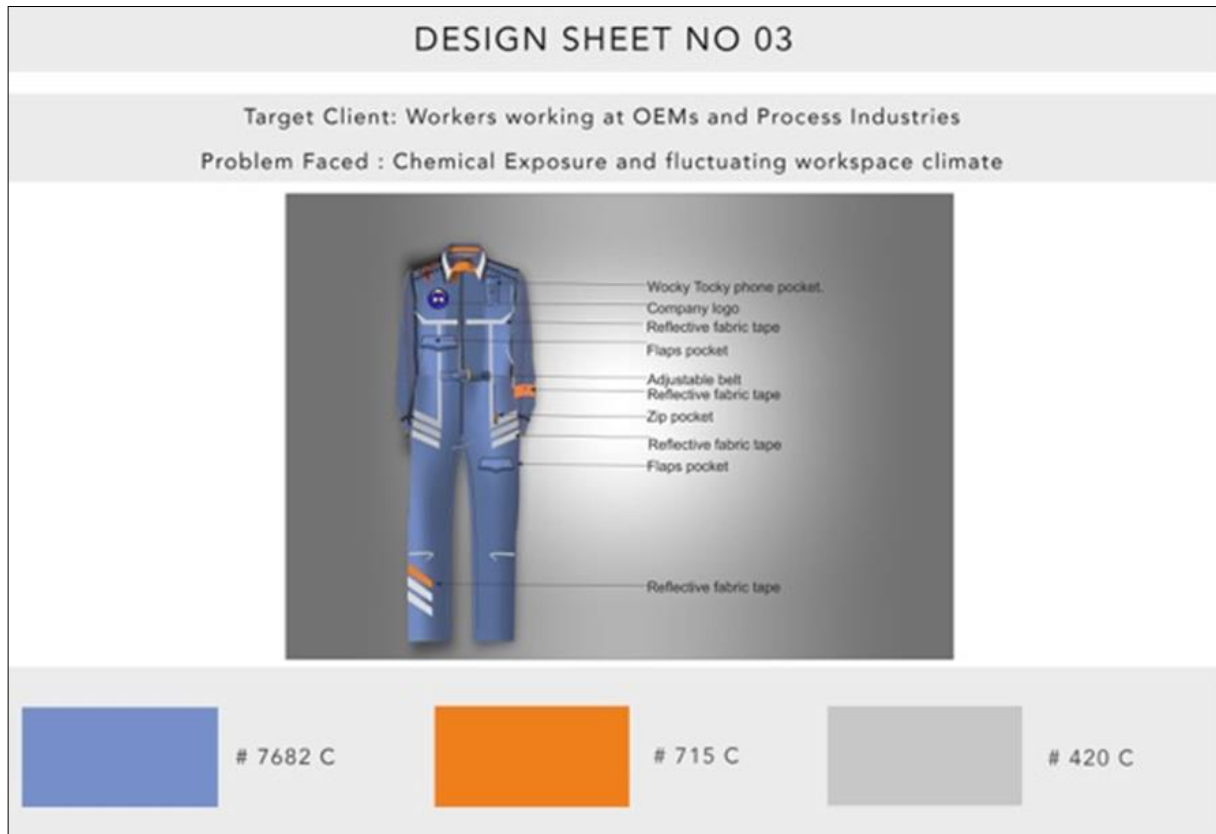


Plate VI: Design sheet 3 comprising of an overall design proposed for the workers

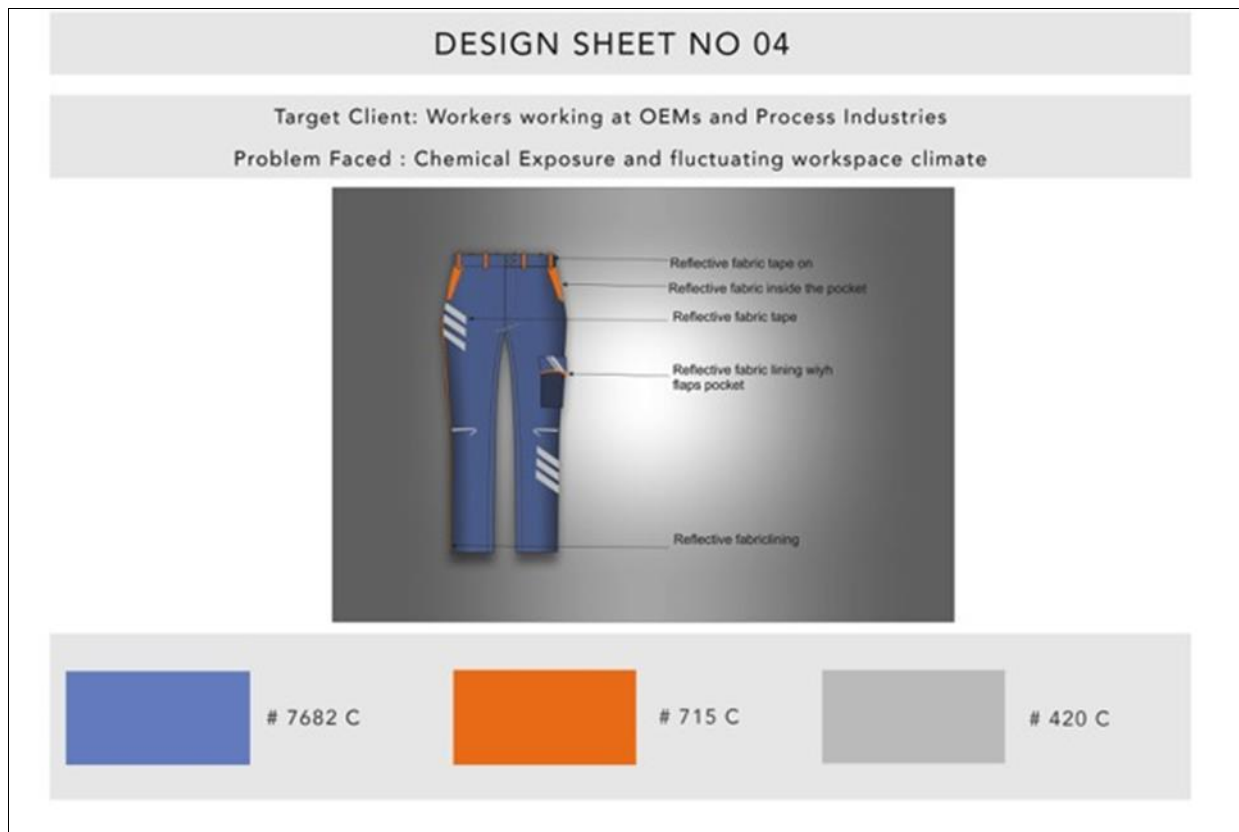


Plate VII: Design sheet 4 comprising of a trouser design proposed for the workers



Plate VIII: Design sheet 5 comprising of a shirt design proposed for the workers



Plate IX: Design sheet 6 comprising of an apron design proposed for the workers

Conclusion

In the range of everyday fashion, the design is a means of achieving a positive reaction from an observer and potential customer. It is human nature to respond to the visual experience of an object, meaning the surrounding objects as well as clothing and other product for personal everyday use.

The acceptance or rejection of a product crucially depends on the visual experience and psychophysical reaction. The aesthetics of a design affect the success or failure of a clothing system based on how it makes the wearer feel, scope for personal expression, and enables the physiological functions of clothing. In protective textiles as well the

importance of human reaction to positive visual instincts should be considered an important factor. There is growing evidence in present times that fashion has a strong influence on the perception of protective clothing. This is also seen, as there are now fashion shows especially to exhibit protective clothing. One such fashion show is A+A, held in Dusseldorf, Germany.

The present protective clothing has been many times evaluated mainly from the viewpoint of its protective performance. However, according to the ever-increasing requirements for protective clothing, the end user expects more comfortable and functional protective clothes. This has resulted in changes in approach when designing and evaluating individual components of a clothing system. This attempt at making a user-needs-driven design methodology to address a breadth of technical, functional, physiological, social, cultural, and aesthetic considerations that impinges on the design of clothing with embedded technologies. These aesthetically rich protective wear not only ensures the safety of the wearer but also comes with comfort and the wish to wear it instead of compulsion. This practice will also promote uniformity in the industries when not just workers but supervisors and safety officials adorn these uniforms, and aesthetics play a vital role in motivating them.

“For you to sleep well at night, the aesthetic, the quality, has to be carried all the way through.”- Steve Jobs.

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