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Protective textiles for petrochemical industries and OEMs : A solution for providing protection, comfort and efficiency of well being

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ABSTRACT

Fibre development has evolved over the years, first as conventional fibres, then high functional fibres and later as high performance fibres. Protective textiles, part of technical textiles, are a blend of innovations and technology. They comprise of all textiles and products based on the same that are known for their performance or function instead of aesthetic characteristics. Workers wearing these textiles are prone to various risks and each industrial sector has different requirement of protective textiles. The user application for PT include vapor protection, dust and dirt, spray paint, dry chemical handling, electric shocks, acids, flame for the petrochemical and mechanical industries. The performance requirement of all types of PT demand the balance of very different properties of drape, thermal resistance, liquid barrier, anti-static, stretch, etc. the seemingly contradictory requirement of creating a barrier, for e.g. towards heat, chemicals, bacteria and breathability in high functional clothing has placed challenging demands on new technologies for producing fibres, fabrics and clothing designs. Performance level of any PT depends on the nature of hazard, type, design and characteristic features of Protective Textiles. This paper aims to outline the innovations in high functional and high performance fibres for application in Protective textiles and to explore the ever evolving fabrics and fashion landscape and merge innovation to drive extended longetivity, beauty and performance of the protective textiles for work wear in industries. In this perspective review, we report the recent trends in the performance and comfort properties of the Protective Textiles available. Research methodology will include a detailed survey across these industries, to do the assessment and need of protective textiles for various applications. A review of various innovations has been done responding to the various requirements at the job site in mechanical and Petrochemical Industries and needs to be updated. Encouragement of new ideas needs to be linked through to the potential end-workers needs and requirement. This paper has created a direct correlation between the hazard and the protective material and this is viewed as the full solution. A need for improvement exists where a manufacturer knows how the clothing is being worn by the worker. All the safety Professionals of various Industries have learned experiences but as the saying says ,'One can still teach an old dog new tricks'.

Key Words : Safety, Protective textiles, Functional finishes, Hazards, High performance fibres

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INTRODUCTION

Overview :

From the early Chinese and Egyptian civilizations, fibres have been utilized in their technical capacities. They were used to make papyrus mats for making stronger foundations of Buddhist temples and Pyramids. Similarly the warriors of Mongolian armies saw use of silk as semi technical application for comfort and also to reduce penetration of incoming arrows and enable their subsequent removal with minimal injury.

The 21st century has witnessed an extraordinary period of innovation in textile science and new materials have transformed the familiar functions of textile to the advance: fabrics change color, protect wearer from chemical, electrical and mechanical radiation, fabrics can collect solar energy, etc. Performance level of any Protective textiles depends on the nature of hazard, type, design and characteristic features of the PPE (Kilinc, 2013).

Since ancient times, humans have used various chemical and physical methods to modify cloth for aesthetic and functional purposes. Increasingly consumers expect their clothing to be comfortable, regardless of environment and activity. Branson and Sweeney (1991) built upon the work of earlier scholars to develop a framework for comfort assessment based on physical, physiological and psychological factors. Fabric properties such as thermal transmission, moisture transport, and hand are known to influence comfort assessments.

Adams *et al.* (1994) proposed the Garment Impediment Index model designed to specify the degree to which clothing – particularly protective clothing impedes task performance. Fabric finishes that improve the protective function may concurrently increase the impediment index by contributing to one of three immediate effects: compromised movement, physiological responses such as increased heart rate or core temperature, and unpleasant thermal or sensorial sensations felt by the wearer. The net result of these immediate effects may be reduced productivity.

The increasing demand for high value added functional PT is a driver for the modernization of the more traditional textile manufacturing industry producing a clear positive impact on the competitiveness of the sector. PT are part of the PPE family and represent a specific area of the advanced technical textile sector.

Personal protective equipment :

Personal protective equipment (PPE) is used on a daily basis by millions of people all over the EU, voluntarily or as a result of EU legislation. Textiles and clothing represent an area where PPE is an important area of attention. On a global scale it is an area of much research. Safety and comfort are becoming more and more important and these aspects must be in balance. Uncomfortable systems will not be used and put safe working at risk. Thus there is a continuous need for technological innovation to improve the effectiveness of PPE systems. Specialization and specific combinations aimed at use under well-defined conditions contributes to finding a good balance between comfort and safety.

Protective textiles :

Since ancient times, humans have used various chemicals and physical methods to modify cloth for aesthetic and functional purposes. Two broad categories of function have become critical in modern textile production, namely the comfort function and the protection function. Increasingly consumers expect their clothing to be comfortable, regardless of environment and activity. Natural

fiber producers promote the comfort aspects of their products as a major incentive for consumer comfort performances (Crumbley, 2009).

Technical textiles are mainly used for the performance/functional properties rather than the look/aesthetic characteristics. Fabrics with industrial applications are also classified as technical textiles.

Protective textiles are classified as woven, knitted and non-woven. Some textiles are created using specialized techniques like 3D weaving, braiding using natural/man-made fibres, spacer fabric knitting and finishing technology. Presently, high performance fibers are commercially available for industrial and technical applications in a wide variety. The applications of these fibres are seen as protective wear developed for impact protection and in textile reinforcement. Many of the "high-tech" fibers, such as Nomex® (DuPont), Kevlar®, and Twaron® (Acordis) aramids, , PBI, Kermel® (Rhone- Poulenc), Spectra® (Allied) HDPE fibers P84® (Inspec), carbon impregnated fibers, aramid spunlace materials, fiberglass, even steel, copper, and other metal fibers have applications in the protective clothing areas.

Static and dynamic system :

Static systems provide passive protection simply by being part of the wearers outfit or Separating the "danger area" form the worker. Dynamic systems are more intelligent, use sensors, communication technology and actuators as part of the textiles.

The current trends are that there is a shift from mass production to mass customization and personalization. Fashion is increasingly playing an important role in achieving acceptance of personal protective clothing. Development trends for innovation and technology are in the areas that follow: Polymer technology: research into new fibre materials, composites and coatings is going on a global scale. The embedding of functional properties both in the fibres and in coating is subject of intensive research.

About petrochemical industry and OEMs :

A Petrochemical refinery primarily works to split crude oil in various fractions which can be reprocessed as useful products. The type of crude oil or products will determine the type, size and number of process units required at the refinery. A refinery is a maze of interconnected units of tanks, distillation towers, furnaces, pipes, heat exchangers, fittings, pumps and valves. The crude oil refineries produce various fuels, petroleum solvents, lubricating oils, petroleum wax, greases and asphalt. The products and the processing/refining of these products are both hazardous. The equipment and plant are modern and the processers are mostly automatic and totally enclosed. If adequate maintenance is carried out then the routine operations at the refineries possess a low risk of exposure. However, a potential of hazardous exposure is always there. A health risk assessment in petroleum refineries suggested that fatality rate in this industry is 7 times more than general industry and 2.5 times more than construction industry.

The acronym OEM (Original Equipment manufacturers) has come to be associated with Product engineering and manufacturing, sub-assembly manufacturing and even component manufacturing. OEMs manufacturers design, engineer and manufacture complete products and systems. Manual and Pneumatic Control valve OEMs have various job works which were identified and required appropriate PPE. Jobs works like Welding, Spray Painting, Molten hot splashes of hot liquids, oil and grease, metal pieces on (Kilinc, 2013).

Fabrics and Materials as a barrier :

Safety is obtained primarily by choice of materials of the construction: Aramides, Kevlar, Dyneema, polycarbonate, and the like. The secondary option is the use of coatings. A broad selection of coatings is available: PVC, Polyurethane, and ceramics. Nanocoatings offer specific benefits in soil and water repellence. The third option is the use of additives to obtain specific properties: flame retardants are a good example, but also UV absorbents to protect the worker from UV radiation, carbon fillers to reduce electrostatic charging. The shape/geometry of the fibres are also critical, we see the development of hollow fibres and fibres with surface structures to enhance comfort properties like moisture transport or cooling effects. In addition the use of conductive yarns, carbon, and copper, to avoid electrical charging is widely applied. The architecture of the textile is of great importance.

Knitted and woven textiles are used for the greater part. Non-wovens are being applied to obtain 2D stability as interlinings or between layers for comfort reasons, the relatively new 3D woven and knit ware are areas of further improvement: thickness can be tuned to specific needs. They provide comfort enhancing effects, impact benefits and allow for the incorporation of e.g. shear thickening materials in impact protection.

Coatings are a separate area of development. The use of membranes like Goretex or Sympatex, thin coated membranes that transport vapour (sweat), but stop water are in use in many applications. Comfort is greatly enhanced by these materials. In combination with specific fibre geometries comfort is greatly enhanced. The combination with Coolmax fibres or other fibres extent the comfort factor. In this respect self healing materials are of importance. If coatings can repair themselves are being damaged that would be a great improvement. Coatings can be combined with other functionalities like breathing, skin friendliness, non-static, anti abrasion, anti microbial, flame retardant, etc.

Finishes :

Functional finishes for protection and comfort have gained importance recently in Indian scenario. These improve the protection characteristics of clothing for workers who are involved in the specific job work where hazards may be encountered. Flame resistance, liquid barrier, antimicrobial and UV protective finishes. Phase change materials (PCMs) and nano-technology are some of the newest approaches to providing 'smart' finishes impacting comfort and protection.

Finishes to improve comfort :

In its broadest terms, clothing comfort is often described as consisting of thermal and sensorial comfort. Thermal comfort is determined by the ability of the body to have balanced heat exchange with the environment. Mechanical napping finishes and fulling of wool have been used to improve the insulation characteristics of fabric for centuries. Recent developments in finishing have addressed the need for achieving function such as water resistance or flame resistance without sacrificing hand properties.

Finishes for improving thermal regulation :

Clothing creates a buffer layer which alters the heat transfer rate from the human body to the environment. The heat transfer rate is determined by the nature of the clothing fabrics and air layers created. Phase change materials are relatively new technology that can be used in a wide array of applications to aid in the process of thermal energy transfer. Applying phase change

materials to textiles and clothing by finishing creates an additional buffering effect that minimizes changes in skin temperature to maintain the comfort of the wearer (Mansfield, 2004). Today PSMs have found wide application in the fields of PC, medical textiles, sportswear among others. PCMs can be incorporated into textiles using coatings with embedded PCM microspheres. Such coating may be based on acrylic or polyurethane, and can be applied using processes such as knife-over-roll, knife-over-air, pad-dry-cure, dip coating and transfer coating (Mondal and Mishra, 2008). Textiles finished with PCMs are considered smart textiles. Static thermal resistance is greater in coated PCM fabrics than in untreated fabrics, but this can be attributed to the binder material used to coat the fabric, which closes pores in the textile (Zhang and He, 2001). The key role of PCM coated fabric is to serve as a buffer when a person goes from a neutral environment to a cold one.

Finishes for improving moisture management :

Moisture management can be defined as the engineered or inherent transport of water vapor or aqueous liquid (perspiration) through a textile. It is an integrated function of wetting, wicking, liquid moisture transport and surface evaporation. Moisture vapor or liquid absorbed from the skin side needs to move from the fabric inner surface to its exterior surface to vaporize. Sampath and Senthilkumar (2009) introduced a moisture management finish (MMF) on microdenier polyester fabric based on aminosilicone polyether copolymer.

Need for the study :

Many professional workers are confronted more or less daily with extreme dangers in the workplace, both outdoors and indoors. Textiles producers are supplying garment makers with an extensive range of top-quality and technologically advanced fabrics that form the basis for protective clothing. Important is that clothing does not hinder but facilitates their tasks. Those fabrics must be safe, but also flexible and comfortable, because professional workers must not have their freedom of movement restricted. That is why the current textile producers collaborate closely with fibre manufacturers, chemicals suppliers, laboratories, governments, garment makers, laundries and end users. The fabrics must provide protection against a multitude of dangers. From heat, flame, drops of molten metal and splashes of liquid chemicals, to electrical arc, static electricity and poor visibility. The textiles selected must provide other properties important for a worker's daily task such as breathability, moisture regulating capacity, comfort, washing convenience and durable character. The hazardous risks can only be met at times by combining the materials and fabrics with a multilayer solution. This leads to the development and market introduction systems, with each protective layer having been developed for specific functionalities.

Utility workers work in an industry supplying gas, heat and electricity. All through high-grade distribution grids. Energy suppliers provide numerous services and products that involve a multitude of risks. Tasks differ greatly: checking the electricity meter, laying a main underground, or checking the power lines at great height. They operate in a range of different working and weather conditions. Outdoor working conditions require durable fabrics, fabrics that also provide protection against a range of risks. Poor visibility at the roadside demands fluorescent clothing. Furthermore, a worker's movements can generate a static electric load in the clothing, sometimes to extremely high voltages. This static load must be discharged from the clothing in a controlled manner. Failure to do this creates a major risk in an explosive environment. In addition, employees in the energy sector can also be confronted with heat and flame, electrical arc, welding sparks, chemical splashes and foul weather conditions. The safety garments are produced from protective fabrics that offer multi-risk

protection. A typical, high quality product will be made of a blend of Flame retardant plasma polymerized acrylonitrile/cotton/para-aramid/polyamide, which is an Inherently flame-resistant material with good comfort properties (Cool and breathable) strong thanks to para-aramid and polyamide.

Objective of the Study :

The aim of the research is to identify various job works in the Petrochemical Industry and at Original Equipment Manufacturers (OEMs) where appropriate Protective Clothing is required.

To propose the protective textiles for job works identified in the petrochemical industry and OEMs that ensures the safety, performance and comfort of the workers.

Materials and functional solutions have been selected to increase comfort and help prevent dangerous situations.

METHODOLOGY

The sampling frame is based on the Interviews conducted with 20 Mechanical (Including Original Equipment manufacturers) and Petrochemical industries in the Western and Northern region of India. For this study, 300 workers and 50 safety professional, Engineers, scientist have been selected randomly from 20 different Mechanical and petrochemical Industries and OEMs.

The aim of the study is to make a direct correlation between the hazard (like flash fire) and the protective material (fire retardant clothing) and this is viewed as a full solution. A study was conducted in a phased manner in 2 parts

Phase I :

- Identifying 20 Mechanical and Petrochemical Industries through snowball sampling, personal Contacts and Internet.
- Assessment of clothing needs of workers in process industries (350 workers).
- Referring various libraries for literature survey collected secondary data.
- Sample Selection: The total sample size comprised of 20 industries. (Pan India).

Tools and Techniques of data collection - Interview Schedule was designed for proprietors of Industries and Industry safety professionals (30 in no.), their supervisors and Engineers (20 in no.) and workers (300 in no.).

An Interview was conducted with the workers and safety professionals to understand how the workers actually do their job, how they use their personal protective equipment and how they can be exposed to multiple hazards in completing their everyday task. As a result a direct correlation between the hazard and the protective material has been proposed and this is viewed as the full selection.

Phase II :

Identification of the right Protective Textiles for the Industries identified and the suitable Protective Textiles based on the protection requirement.

The authors propose selection of smart textiles based on the hazard they are prone for.

Textile Industry contributes majorly to increase the safety of workers on 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

Table 1 : Chemical and petrochemical protective clothing design types by body area

Body area	Type
Entire Body	Totally encapsulated suit
Torso, head, arms, and legs(excluding hand, feet, and face)	Hooded Coveralls
Torso, arms and legs	Coveralls
Top torso and arms	Coat or Jacket
	Lab coat
Bottom torso and legs	Pants
Torso(front) and arms	Sleeved apron
Torso (front)	Hood with visor
Head and face	Hood
Head	Booties
Foot	Boot or Shoe cover

Protective Textiles are essential.

In light of extensive utilization of Protective textiles in the Mechanical and Petrochemical Industry this paper attempts to discuss Protective textiles under this category highlighting their importance and scope of versatility.

RESULTS AND DISCUSSION

Various Petrochemical and OEMS for Control valve and butterfly valves were assessed. The job works which had the demand of appropriate Protective work wear were identified through observation method and interview conducted with safety professionals and engineers.

The industry exposes workers to numerous risks that demand protective solutions. The level of protection and the clothing requirements are defined by the working conditions and the chemicals present, protection against the release of explosive substances, working with flammable chemicals, and toxic chemicals. This work involves lots of movement.

Friction generates a static electric load in the clothing, sometimes to extremely high voltages. If this static load discharges the clothing in an uncontrolled manner, then it can create an explosion due to sparks in an explosive atmosphere. There are also production processes with flammable raw materials. Or pyrophorous substances are handled that ignite spontaneously on contact with air or water. This demands wearing clothing that is exceptionally heat- and flame-resistant But that can also repel chemical splashes.

Moreover, various production processes take place in the petrochemical plants that expose workers to extremely high or low temperatures. Their clothing must regulate moisture effectively to prevent heat stress. Typical an overall in these conditions is made of 93/5/2% meta-aramid/para-aramid/carbon fibre (for release of static electricity). In addition these workers wear helmets (made of polyethylene/PVC, or Acrylonitril-butadieen-styreen (ABS), could be glass fibre reinforced), gloves, goggles and boots

Analysis of phase 1 defining the need for the study :

In the past where traditional design of personal protective equipment (PPE) was driven by functionality and comfort, manufacturers are now increasingly offering products styled with more than a nod to high- street fashion. To offer the appropriate Protective textiles for the job work

identified in Industries the authors have suggested a list of textiles for the chemical, mechanical, thermal and electric protection.

Not believing that PPE is necessary for the job work or considering it too uncomfortable makes the employee vulnerable. According to the survey done by the authors in various OEMs and Petrochemical Industries. The results reveal that 71 percent of safety professionals observed workers not wearing PPE when it was needed, with 29 per cent claiming they had noted this unsafe behavior on multiple occasions. Manoj Ramsanhei, Managing Director of Uniflow Control Valves, said this rate of noncompliance poses "a serious threat to worker health and safety."

The most common reason for PPE noncompliance (at 69 %) was the belief that PPE was not necessary. The compliance of PPE was less when the workers found it to be too hot, uncomfortable, poor fit, unattractive or not available near the work.

The authors propose their top objectives for the research conducted for encouraging PPE compliance: improving education and training programs (61 %) and increased monitoring of employees (48 %). Other strategies included; tying compliance to individual performance evaluations; developing incentive programs. Purchasing more comfortable PPE and purchasing more stylish PPE.

Of the 111 participants surveyed online and at personal interaction from June 17 through March 18, 63 per cent were safety directors or managers, while the other 37 per cent were industrial hygienists, facilities or general managers, environmental managers or held other positions. All survey respondents said they were responsible for purchasing, selecting or influencing the purchase or selection of PPE (ehstoday.com/ppe). In Public sectors there is no problems for finances for appropriate PPE but in few Medium Scale Industries and OEMs safety awareness and finances for appropriate PPE was lacking.

The following trends are found in the Indian market for PPE's:

- Protection for employees in industrial production is increasing.
- The import of PPE's from other countries is increasing however, these products are often expensive.
- People and companies are more and more conscious regarding to PPE's.
- Fashionability is an increasing factor for PPE's.
- Companies are strengthening their corporate identity with PPE's.
- There is a growing demand for PPE's with multiple functional properties.
- Standards for PPE's will keep developing because of practical experience and evolution in industrial processes.

PPE textiles that are pretty, comfortable and of good quality are worn with more pleasure and regularity than an old fashioned, boring outfit that is not comfortable. PPE's are becoming more fashionable every year and this is an important factor for employees to bind and keep their employees. Integrating fashionability and safety are also a great opportunity for producers in ways of innovation and versatility. Corporate identity is a marketing tool that companies want to strengthen by developing unique PPE's for their employees.

Another trend is a growing demand for "Multi-standard" PPE's. These are PPE's which are used for several conditions and against multiple risks. The importance in this product is that all employees in a company can be dressed equally no matter what their function or task implies.

For producers, it means that they have to combine different types of protection in clothing with an optimal comfort for the carrier. The comfort in these "Multistandard" PPE's is very important, because when a PPE isn't comfortable there is a good change it will hardly be worn by employees (safety and fashion at work).

Potential job works and hazards associated :

If one considers the position of a person in a working environment one can distinguish some typical characteristics or interactions where protective materials or systems interfere:

1. Interaction with the machine or object that is being used or worked upon.
2. Interaction with the working environment.
3. Interaction between co-workers/colleagues.

In all of these interactions materials are being applied to perform certain tasks. For example, Protective gear that fire-fighters use: complex high tech suits, multilayer, fire resistant, and nowadays fitted with built-in communication systems. Comfort has become a major issue. In these solutions to specific problems materials, and in many cases textiles, play a dominant role. Thus we may conclude that functional textiles offer solutions for protective clothing for work wear, hazardous industrial occupations and extremehazard protection.

Appropriate protective textile solution from existing textiles and chemicals for finishes:

With Industrialization, the safety of human beings has become an important issue. Major innovations in the development of heat resistant fibres, acid and alkaline finish, waterproof breathable coatings, flame retardant finish (durable and non durable) and others. While selecting Protective textiles it is important to identify those areas of the body that are exposed to the maximum amount of petrochemicals, oil spills (Easter and DeJonge, 1985).

There is a need to develop Protective Textiles i.e. light weight, comfortable, economical and acceptable to workers. After the survey conducted it was seen that the fabrics used were 100% cotton and 70/30 Polyester cotton blend, as they are commonly used for uniforms supplied to workers in various industries.

No material provides complete protection from all hazardous substances. Chemicals can gain access to the wearer or can affect clothing material in three ways: permeation, degradation and penetration.

Permeation is the most important indicator of the usefulness of a particular chemical protective material. Permeation is the process by which a liquid or gaseous chemical passes through the material at the molecular level. Some chemicals can permeate clothing material in only few seconds, and if these chemicals are toxic, the protective qualities of the clothing material are not sufficient for use at hazardous spill sites.

The second means of chemical intrusion is degradation this is the deterioration of the clothing material caused by the action of a chemical. Degradation may change bulk properties, such as tensile strength or may result in the dissolution of small areas of the material.

Finally, penetration is the flow of a liquid or gaseous chemical through closures, seams, pin holes. Penetration does not pertain to the type of material, but rather to how it is used or abused. As most materials are more or less resistant to abrasions, pin punctures etc., penetration is more relevant to the way garments are put together than to what they are made of.

Recognition of these areas could allow the worker to protect the areas of maximum risk and allow greater flexibility for comfort in other areas. The type of job being conducted, the proximity with chemicals and various other hazards causes different areas of body to be exposed to varying amount of chemicals. Research has been conducted on deposition patterns of various petrochemicals for mixers, loaders and applicators, and it has been found that the extent of exposure is specific to the kind of job undertaken.

There is a variety of Personal Protective clothing available for specific work situations. However,

Table 2 : Selection of material for the construction of protective clothing as per the nature of hazard

Material	Kind of Hazard	Application	End Use Industry
Denim base (100% cotton twill 2/1) (Finishes applied for thermal regulation; flame resistance; antistatic; acid and alkaline proof; moisture management; antimicrobial; UV protection)	Hot liquid, moisture, water, chemicals exposed while Spray painting, Welding, petroleum product, flying particle while on Lathe Machine, electric shock, skin protection	Thermal Mechanical Biological Chemical	Petrochemical Industry, Chemical Industry, Workshops, OEMs
Kermel Denim	Heat, hot substance, sparks	Thermal Mechanical	Boiler Manufacturers, Fabricators, Vessels manufacturers, Reactors Manufacturers
Plastic, PVC	Hot liquid, moisture, water, petroleum product, acid, alkali, spark, falling body, flying particle, electric shock, skin protection	Thermal Chemical	Petrochemical Industry, Chemical and Agrochemical Industry, Paper Industry
Rubber	Hot liquid, moisture, water, acid, alkali, electric shock, machinery, skin protection		Petrochemical Industry, Chemical and Agrochemical Industry, Pharmaceutical Industry, Food Industry, Paper Industry
Chrome leather	Abrasion, sparks	Mechanical	Boiler Manufacturers, Fabricators, Vessels manufacturers, Reactors manufacturers
Canvas	Flying particles, sharp edge, abrasion, machinery		OEM's
Tyvek	Hot substance	Petrochemical and Chemical industrial cleaning and maintenance, and land clean-up	Petrochemical and 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 intervention, the gas supply sector, typical chemical industry applications	oil and gas industry , petrochemical Industry

Table 2 contd….

Contd… Table 2

Reflective fabric	Hot liquid	Visibility	Typical Chemical Industry, Petrochemical Industry
Cotton wool	Heat, sparks, machinery, skin protection	Mechanical Thermal	OEM's, Chemical Industry, Petrochemical Industry, Foundaries
Woollen fabric, worsted fabric	Hazardous liquids (Sulphuric acid, hydrochloric acid, nitric acid), acid resistant, Flame, sparks	Chemical Thermal	Chemical Industry, Petrochemical Industry
Cotton canvas	Sharp edge, abrasion	Mechanical	OEM's, Fabricators

selection of the most appropriate form of protection is very complex, as safety mobility and dexterity, comfort and cost must be balanced.

Conclusion:

Selection of appropriate PPE design in relation with comfort and willingness of workers to wear the products is a great area of development. Scientific studies are going on to establish design guidelines for textile products with optimal protection but keeping comfort as a key design issue at the highest level of priorities. Thermo physiology is the science area that will lead to new breakthroughs in this area (extensive list of work of prof.HeinDaanen).

a. Safety is obtained by choice of materials for a textile construction, including the use of coatings with special properties, application of specific additives and the use of special designed fibre shapes.

b. The architecture and ultimate construction and the combinations with other materials result in products that respond adequately. This is of great importance because of the balance comfort – safety. But a lot can be improved in this respect.

Due to the enormous research area of smart textiles a lot of development is aimed at the integration of new technology for application in PPE. This results in complex products that enhance both passive and active safety.

From this research the following may be concluded: 1. Safety is obtained by choice of materials for a textile construction, including the use of coatings with special properties, application of specific additives and he use of special designed fibre shapes. 2. The architecture and ultimate construction, and the combinations with other materials result in products that respond adequately. This is of great importance because of the balance comfort – safety. But a lot can be improved in this respect. 3. Insight in human behaviour, ambient intelligence and systems technology will lead to new routes for product development and a more active approach and higher levels of safety on the workfloor. Consequently there is a lot of research going on that is aimed at improved materials and systems. Also due to the enormous research area of smart textiles a lot of development is aimed at the integration of new technology for application in PPE. This results in complex products that enhance both passive and active safety. Especially the commissioners, government and industry, must pay a lot of attention to specifying the required properties that a product should meet under the specific conditions.

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