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New Methods of Maintenance and Cleaning of Firefighter's Protective Clothing by Dry Cleaning

Abstract

The condition of personal protective equipment (PPE) worn by firefighters has always been of paramount importance. In this article, the authors briefly describe the work of firefighters, based on analysis of domestic and international literature and their own professional practices, and then the types of contamination of clothing and the health risks they pose. A number of new technologies for the complete removal of contaminants from protective clothing are already on the market, but due to their higher cost, they are unlikely to fully replace the traditional cleaning currently used, but can be an excellent complement to current cleaning processes. The authors then proceed to examine the innovative technological solutions that are currently available in the field of cleaning firefighter protective clothing, before finally proposing the introduction of certain methods.

Keywords: firefighter, personal protective equipment, contamination, cleaning, washing

Introduction

The work of firefighters is more dangerous than everyday life, but this does not end when the duty is finished. In order to ensure the safety of firefighters and the public, it is essential that they have adequate theoretical and practical knowledge, experience, high mental and physical endurance and communication within the team. In addition to these, the personal protective equipment (PPE) and fire equipment they wear complement the previously listed conditions for accident-free and healthy work.[3]

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[3] Pántya–Horváth 2023b: 88.

For preparing this article, the authors used the methods of analysing selected literature as international and Hungarian scientific papers, examining international wide databases about fire cases and product data about their capabilities from producers in the field of protective clothing. The authors used their own experience in fire safety from both the occupational health and intervention side. Given the scarcity of publications in this area of research, the available resources were limited.

Following the conclusion of an intervention and the departure from the scene of an accident, there are still a number of tasks that must be completed. Failure to do so could have a detrimental effect on the physical integrity and health of the firefighters. In addition to the inspection of professional equipment and the subsequent professional analysis of the case, the proper handling and cleaning of PPE plays a prominent role. This is because countless contaminants that are harmful to the human body can get on its surface or get into the fabrics (e.g. protective jacket).[4] Before embarking on an explanation of the topic of cleaning, it is advisable to take a brief detour into the realm of firefighters' daily work and the potential pollutants that they may encounter.

In addition to extinguishing fires, firefighters are also responsible for carrying out technical rescue and fire investigation tasks. The exact definition of these tasks in Hungary is provided by Act XXXI of 1996 on Fire Protection, Technical Rescue and Fire Brigades. Different activities involve various sources of danger, and PPE offers sufficient protection against most of them. Horváth briefly explains this topic, mentioning the dangers and psychological stress that arise during the performance of sports tasks required to maintain physical condition.[5]

For a detailed overview of the firefighter's job and the associated dangers, the risk assessment at the employer can provide adequate help, which is provided in Hungary by the Act XCIII of 1993 on Labour Safety. Furthermore, the document delineates the specific dangers associated with each job, the circumstances that exacerbate these risks, and the measures implemented to mitigate them. By furnishing the employer with a comprehensive understanding of the occupational hazards faced by employees, this document facilitates the procurement of the requisite PPE.

Following the purchase of this equipment, it is of the utmost importance to disseminate comprehensive information to all staff members regarding the correct use, cleaning and storage of the provided clothing. As the manufacturer always prepares a comprehensive user manual, its content can be integrated into the subject matter of the educational material (in addition to general practical experience). Although this may not appear to be a significant factor at first glance, it is nevertheless a necessary condition for everyday life. This is because any object that is used on a regular basis and that is subjected to professional maintenance will inevitably increase its quality of life. This is also true of personal protective equipment, which will maintain its ability to protect for a longer period if it is subjected to the correct maintenance procedures, which is also economically advantageous, since it reduces the number of purchases. The International Association of Fire Services (CTIF) provides statistical data on fires

[4] Fent et al. 2017: 801–802.
[5] Horváth 2022: 50–52.

in different countries for several years. Highlighting one of them, Figure 1 shows that the number of injured firefighters increased during the period under review. Although the reasons are not indicated, the increasing trend certainly provides a basis for the development of personal protective equipment.

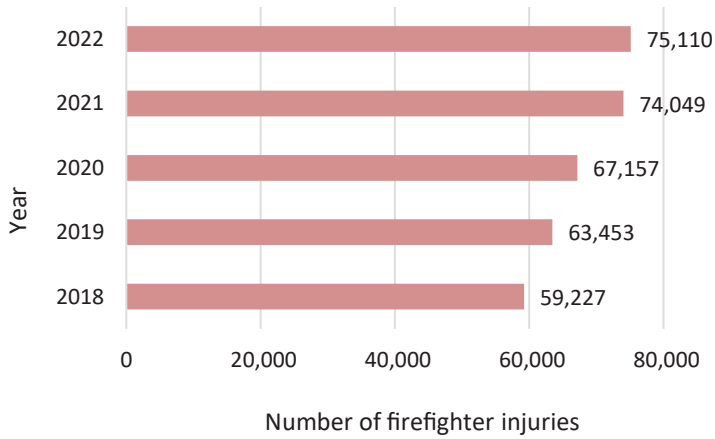

Figure 1: Trends in firefighter injuries in the countries of the World in 2018–2022
Source: compiled by the authors based on www.ctif.org/world-fire-statistics

It's important to note that different types of contamination require different cleaning methods. This is why it is also important that the staff receives adequate information in advance and regularly about the handling of personal protective equipment. Protective clothing may also become contaminated with substances of medium or high risk to human health, including blood, urine, faeces, and various chemical substances. In such instances, it is recommended (or indeed obligatory) to remove the protective clothing immediately and place it in a securely sealed bag for subsequent decontamination or to perform the decontamination procedure on-site.[6]

A significant number of international literatures address the issue of pollutants affecting firefighters, which can result in long-term illness due to their carcinogenic properties. One such group is the group of polycyclic aromatic hydrocarbons (PAHs), which are predominantly formed during the incomplete combustion of organic substances. Their natural sources of origin are, for instance, forest fires, but they can also be found in tobacco smoke and exhaust gas, and can also enter the human body during grilling of meat products.[7] A number of studies have reported the presence of PAHs and other pollutants on the PPE of firefighters, which subsequently enter the body through inhalation or contact with the skin. It is therefore important to pay sufficient attention to the proper cleaning and disinfection of clothing. In their experiment, Mayer et al. examined the effect of washing on the PAH concentration

[6] Decontamination is a combination of processes that removes or destroys contamination so that infectious agents or other contaminants cannot reach a susceptible site in sufficient quantities to initiate infection, or other harmful response.
[7] See: www.cdc.gov/biomonitoring/PAHs_FactSheet.html

on the given clothing. It was demonstrated that the concentration of PAHs could be significantly reduced by washing a contaminated garment, however, its presence could be detected on the new garment after washing, indicating cross-contamination.[8]

Regardless of the chosen method, the primary objective is to safeguard human health, with prevention being contingent upon economic and technical feasibility. The authors' objective is to present, through the examination and analysis of the methods presented in the following chapters, technological achievements that have long provided a satisfactory level of solution or have not yet been widely used as novum, but show convincing results.

Washing

The use of household and industrial washing machines has become widespread in most fire departments for the cleaning of firefighting protective clothing. Due to their smaller capacity, household washing machines can only wash a maximum of one item of clothing (trousers or jacket) at a time. This is not necessarily the most optimal solution in terms of time required and amount of water used, but it is sufficient to remove minor, non-infectious types of dirt. In contrast, industrial washing machines are now capable of accommodating multiple items of clothing. Their robust construction also allows for a longer expected fault-free lifespan. Furthermore, some manufacturers offer users the option to select an appropriate washing programme for the specific clothing in question (e.g. Protective Apparel programmes).[9] This is particularly beneficial for firefighting protective clothing, as preserving its protective ability for as long as possible is of paramount importance.[10]

In the case of washing protective clothing with a washing machine, it is also necessary to add an impregnating agent to the detergent at intervals recommended by the manufacturer. In order to understand the process of impregnation, it is first necessary to clarify the concepts involved. Firstly, it is worth mentioning the term water repellent. The materials in this group (clothing in this case) have the least protection against water. The addition of nylon or polyester during the mixing process is typically employed to enhance the water repellence of the material. The greater the density of the weave, the more challenging it is for water to penetrate. However, this provides only temporary protection. The next group includes water-repellent materials, in which case water is less able to enter the fabrics, thanks to the reinforced structure. The last group with the greatest protection is waterproof, where the given material is able to prevent the entry of water for a longer period of time.[11]

Textile impregnation is a process by which textiles are treated with a coating or substance in order to enhance their properties. This may include the addition of water resistance, stain resistance, flame resistance, or other desirable properties to

[8] Mayer et al. 2019: 139.
[9] See: www.dupont.com/personal-protection/nomex-industrial.html
[10] Bralewska et al. 2024: 1.
[11] See: https://manteco.com/what-is-the-difference-among-water-repellent-water-resistant-and-water-proof-clothing/

the fabric. The impregnation process can be carried out using a number of methods, including spraying, soaking or coating the fabric with a special solution. One common method of impregnation is the application of a chemical coating to the fabric, which is then cured by heat or pressure. This process creates a barrier on the surface of the fabric that repels liquids and prevents stain build-up. Another method of impregnation is lamination, where a thin film is applied to the fabric to provide greater protection and durability. Lamination can be employed to enhance the strength, flexibility, and resistance to tearing or wear of the fabric. This process is frequently utilised to manufacture technical fabrics for sportswear, outdoor equipment and medical textiles.[12]

The application of nanotechnology to the field of textile impregnation has led to the development of superhydrophobic fabrics that repel water and dirt at the molecular level. This cutting-edge technology enables the fabrics to retain their breathability and elasticity while providing excellent protection against stains and moisture. Furthermore, nanotechnology can be employed to create self-cleaning materials that require minimal maintenance and retain their properties after repeated washing.[13]

In the user information document of the Fire Fit 2 protective clothing sold by Rosenbauer, the manufacturer recommends the use of the impregnating agent at least after every second wash.[14] In their list, specific products are displayed (TX-Direct Wash, Hydrob Easydry), so it is possible to choose the right product for us on the manufacturer's website. The Nikwax website states that the TX 10i water repellent elastomer was developed based on EVA (ethylene vinyl acetate), and later became the primary active ingredient in all their products.[15]

In order to maintain the water repellent properties of firefighting protective clothing, it is essential to apply an impregnating treatment to the material on a regular basis. This is typically done during the washing process, which restores the fabric's ability to repel water and other substances. The water repellent surface plays a vital role in keeping firefighters dry and comfortable, and it is therefore crucial to ensure proper maintenance and washing of these garments in order to maintain protection and longevity.

In addition to impregnation, it is worth noting the significance of vapour diffusion, which is also an important aspect of firefighters' lives during an intervention. Physical activity raises body temperature, and the body responds by sweating to expel extra heat. This job is much more crucial in high outside temperatures, where intense physical labour is conducted under severe conditions. Clothing must consequently be fashioned of a material that is both water repellent and vapour permeable. This property is already present in firefighting protective apparel, although there has been extensive national and international research in this field.[16]

Moisture barriers, as a critical component in several applications, are principally constituted of slender, semi-permeable membranes, which are meticulously laminated onto a base fabric that is inherently resistant to fire. This base fabric may either be woven or nonwoven, depending on the specific requirements of the application.

[12] Smith 2010: 3–9.
[13] Jeyasubramanian et al. 2016.
[14] See: www.rosenbauer.com/en/int/rosenbauer-world/products/equipment/protective-clothing/fire-fit-2
[15] See: www.nikwax.com/en-us/how-nikwax-works/
[16] Pántya–Horváth 2023a.

Presently, the technology underpinning these membranes can be classified into three distinct categories: microporous membranes, solid hydrophilic membranes, and bicomponent membranes. These categorisations encapsulate the existing diversity in membrane technology, each with its unique method of moisture regulation, catering to various performance demands in industrial and consumer products. Within the realm of microporous membranes, expanded polytetrafluoroethylene (e-PTFE) membranes are extensively employed in the fabrication of firefighting apparel. Nonporous films, including polyurethanes (PUs) with hydrophilic components, are extensively employed as breathable and waterproof membranes in firefighter suits. Vapour transmission over solid film barriers involves an absorption–diffusion–desorption mechanism. Bicomponent membranes consist of a microporous membrane and a solid hydrophilic film. Most commercially available moisture barriers in firefighter uniforms are bicomponent e-PTFE barriers. Adding a solid hydrophilic layer improves moisture barrier longevity and resistance to water penetration. However, it also increases evaporative resistance, which is highly reliant on moisture content. The study of Gao et al. examines heat transfer via firefighter protective clothing by contrasting several moisture barrier technologies. The findings of this study provide conclusive evidence that hotter environments result in reduced water accumulation within moisture barriers, leading to significantly higher evaporative resistance with bicomponent moisture barriers.[17]

So, in addition to impregnation, research is also looking at heat transfer and vapour permeability, both of which are important in the design of a firefighter protective suit.

Dry cleaning

In the previous sections, the authors briefly described the possibilities and characteristics of traditional washing with water regarding the protective clothing of firefighters. In the following, the so-called dry-cleaning procedures will be discussed, which does not necessarily mean that the contaminated textiles are cleaned in an almost sterile environment.

Dry cleaning is a process that involves cleaning clothes and fabrics without the use of water. This cleaning method is preferred for materials that are less resistant to conventional washing in a washing machine. The process can extend the life of these garments by preventing shrinkage, fading or damage from regular washing. Dry cleaning has a long history dating back centuries. While the modern dry cleaning process was only invented in the 19th century, the concept of cleaning clothes without water has been around for much longer. Its origins can be traced back to the ancient Romans, who used ammonia extracted from urine to clean their clothes. The practice of dry cleaning continued into the Middle Ages and the Renaissance, with various materials such as clay, ash, and even sawdust being used to clean fabrics. The most significant revolution occurred at the beginning of the 19th century, when in 1825 a maid accidentally knocked over a lamp and spilled turpentine on a dirty

[17] Gao et al. 2021.

tablecloth. French-born Jean Baptiste Jolly noticed that after the turpentine dried, the resulting stains disappeared from the tablecloth. After that, he experimented by filling the bathtub with turpentine and then soaking the tablecloth, which became clean after being removed and dried. Dry cleaning soon became popular in Europe and the United States, as it was an effective method for cleaning delicate materials that could not withstand traditional washing methods. During the procedure, the clothes were placed in the machine and then a solvent was added to dissolve the dirt without water. Over the years, technology has developed, becoming more efficient and environmentally friendly. New solvents that are less harmful to the environment have been developed, and machines have been designed to use less energy and produce fewer emissions.[18]

Perchlorethylene (PER) is most often used in traditional dry cleaning. Despite its excellent cleaning performance, PER has several disadvantages, such as its toxic effect on the human body.[19] To avoid this, many alternative solvents are used for textile dry cleaning: hydrocarbon solvents, silicon-based solvents and carbon dioxide (CO_2).[20] In this article, the authors will describe the CO_2 dry cleaning process, as the technology for cleaning protective clothing has appeared in more and more countries.

The use of liquid carbon dioxide in the process of dry cleaning represents a more environmentally friendly alternative to traditional dry cleaning methods that utilise chemicals. This method involves the utilisation of liquid CO_2 as a solvent to clean clothes, rather than the use of toxic chemicals such as perchlorethylene. It is a colourless, odourless, non-toxic and non-flammable gas. In the liquid CO_2 dry cleaning process, this is employed in its supercritical state, whereby it simultaneously exists as a liquid and a gas. Liquid carbon dioxide is combined with a small quantity of detergent and then pumped into a chamber where it is utilised to clean clothes. The solvent is capable of penetrating the fibres of the fabric, removing dirt and stains without damaging the material. The process ensures that the clothes retain their original shape and colour.[21]

A number of international studies have addressed the issue of cleaning firefighter protective gear using carbon dioxide due to concerns about residual impurities from conventional washing methods. These impurities, including potential cross-contamination, can have long-term detrimental effects on firefighters' health. Arjunsing et al. conducted a comparative study examining the effectiveness of traditional washing versus dry cleaning with CO_2 on firefighter protective clothing.

The findings indicated that traditional washing was less efficient in removing high molecular weight pollutants such as PAHs and phthalates compared to lower weight pollutants like phenols. In contrast, dry cleaning with CO_2 consistently achieved high efficiency levels (averaging 95.36%).

[18] See: https://drycleaningca.com/blog/who-invented-dry-cleaning/
[19] Ceballos et al. 2021: 1.
[20] Sutanto et al. 2014.
[21] Madsen et al. 2021: 3–4.

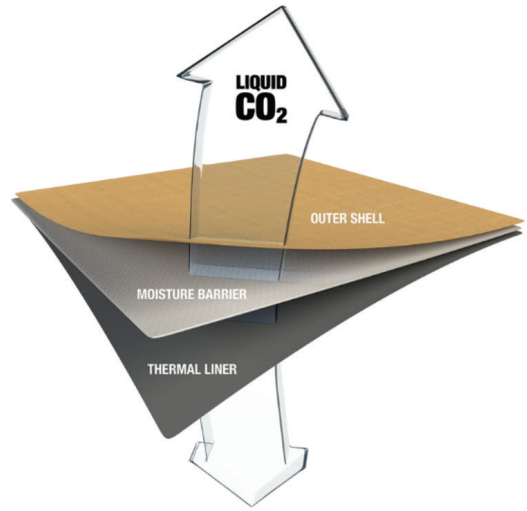

Figure 2: CO_2 cleaning machine and cleaning method
Source: Fire Engineering Staff 2024

It is important to note that the experiment focused solely on liquid pollutants, limiting the ability to draw broad conclusions since firefighters are also exposed to solid pollutants like soot during their duties. Nevertheless, the results provide valuable insights for future research endeavours in this area.[22]

On a domestic scale, the utilisation of dry ice for cleaning purposes has been witnessed in various industries such as plastics and automotive, enabling the cleaning of equipment without disassembly or the use of additional chemicals.[23] In Hungary, ozone-based disinfection is employed for clothes, effectively eliminating diverse pathogens without the need for water or other additives. While ozone disinfection may serve as a beneficial supplementary method for general clothing care, its innovative impact is limited when it comes to firefighter protective gear. Although carbon dioxide dry cleaning services are not yet widely accessible domestically, several international manufacturers have begun offering this option. Notably, Decontex is one such company operating across numerous European countries, specialising in decontamination cleaning services for fire departments. Their website highlights that carbon dioxide dry cleaning not only cleans firefighter protective clothing more effectively than traditional washing methods but also removes dirt from the intermediate membrane material (Deco2 Fire Technology®).[24]

The dry cleaning procedure necessitates a solution for businesses that not only eliminates surface dirt from clothing but also cleanses the fabrics, including the membrane, while maintaining their protective qualities. While the technology's efficiency is not currently economically justifiable for widespread adoption, there are instances, such as when there is a risk of biological contamination, where utilising this method may be advantageous.

[22] Girase et al. 2022.
[23] Tang et al. 2020.
[24] See: https://decontex.com/decon-solution/

Drying

The drying methods employed after traditional laundering play a significant role in the longevity of garments and overall operational efficiency. Following household or industrial washing, fire departments have various options for drying attire. When weather conditions permit and spare clothing is available, it can be advantageous to air dry outdoors. However, caution must be exercised due to intense UV radiation which can compromise material quality and lead to colour fading. Indoor drying reduces this risk but may result in slower drying times and increased humidity levels to consider. A common remedy is the use of a dryer, which effectively mitigates the aforementioned drawbacks either partially or entirely.

A drying cabinet or a free-standing/wall-mounted open dryer is utilised in multiple fire stations. In both instances, the drying process involves the circulation of warm air, powered by electricity. These technological solutions offer expedited and delicate drying, proving beneficial for fire departments facing challenges such as limited space and high humidity that hinder traditional drying methods. This innovation becomes essential when there is a need to dry a larger quantity of protective clothing within a constrained timeframe.

Figure 3: Powered drying cabinet and dryer

Source: https://unimac.com/product/firefighters-ppe-system/firefighter-ppe-drying-cabinet/; www.ppedryers.com/dryers/turnout-gear-dryers/model-ps4-r8/

Summary

Proper maintenance of firefighter turnout gear is essential for safeguarding the health and safety of those working in hazardous conditions. Historically, washing these garments with water has been the conventional approach. Nonetheless, studies indicate that these techniques are often inadequate for the removal of carcinogenic contaminants, such as polycyclic aromatic PAHs and phthalates, which accumulate

in the multilayer materials of firefighting apparel. In contrast, liquid carbon dioxide cleaning technology has emerged as a promising alternative, demonstrating superior contaminant removal capabilities compared to conventional methods.

Liquid CO_2 cleaning functions on principles that exploit its solvent properties, reducing water consumption and environmental impact. Unlike traditional methods that heavily depend on water and detergents, liquid CO_2 utilises a non-toxic solvent that effectively penetrates fabric layers to dissolve and extract contaminants without compromising the protective qualities of the gear. Studies have demonstrated that liquid CO_2 significantly surpasses aqueous washing in decontamination efficiency, thereby enhancing firefighters' safety by reducing long-term health risks linked to contaminated clothing. Furthermore, the environmentally friendly profile of liquid CO_2 positions it advantageously within modern sustainable practices. However, while this method demonstrates potential, continuous research is vital to facilitate widespread adoption among fire departments striving for optimal gear maintenance and firefighter safety.

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