

## **ANYONE FOR A COCKTAIL? UNDERSTANDING THE IMPACT OF TOXIC CHEMICALS ON EXPOSURE OF FIREMEN TO POST-FIRE CONDENSATE**

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### **ABSTRACT**

Firefighters, at a fire scene, post-fire or during training, are exposed to complex mixtures of carcinogenic, potentially/possibly carcinogenic agents and other harmful compounds, despite donning full personal protective equipment (PPE). The mechanisms of the toxicants' permeation inside the PPE or penetration through layers of protective clothing have not been investigated adequately. The knowledge of the transferred toxicants is of paramount importance for firefighters, manufacturers of PPE, decontamination services, regulators, health and safety specialists seeking robust long-term solutions to the problems of repeated exposure to toxic products of combustion. The purpose of this initial study was to identify the chemical nature of the compounds from the fire effluent, produced by burning a mixture of synthetic and natural materials, using high precision analytical methods of Gas Chromatography-Mass Spectrometry (GC-MS) and High-Performance Liquid Chromatography-High Resolution Mass Spectrometry (HPLC-HRMS). Also, it was aimed to investigate whether the movement of toxicants through fabric layers of protective fire suits had occurred. A small-scale laboratory set-up was used to simulate the exposure of two unused fire suit ensembles to heated fire effluent. The fire condensates collected from the exterior and interior of each three-layered ensemble were qualitatively analysed using GC-MS and HPLC-HRMS. It was found that the fire condensate contained a range of polycyclic aromatic hydrocarbons (PAHs), carcinogens and potential carcinogens including tetradecane, phenanthrene, pyrene, polychlorinated biphenyl-126, polychlorophenol, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, 1,1,1-trichloroethane, and bromochloroacetic acid. Both tested ensembles were found to be effective in preventing the transfer of these toxicants through the layers to the interior of protective fire suits.

**Keywords:** Fire Effluent, Toxins, Fire Condensate, Toxicity, Firemen, Fire Suits

### **1 INTRODUCTION**

Firefighting is the most challenging and dangerous profession, associated with a regular and repeated exposure of workers to an array of toxicants. Fire incidents generate a cocktail of toxic compounds comprised of asphyxiant (carbon monoxide, CO and hydrogen cyanide, HCN) and irritant (hydrogen halides HHal, nitrogen oxides NO<sub>x</sub> and sulphur oxides SO<sub>x</sub>) gases, polycyclic aromatic hydrocarbons (PAHs), particulate matter, per- and poly-fluoroalkyl substances (PFAS), volatile and semi-volatile organic compounds (VOCs), heavy metals and other toxic agents, combustion intermediates and by-products, imposing negative impacts on human health [1-4]. The situation is exacerbated when it comes to burning widely used synthetic polymers such as polyethylene (PE), polypropylene (PP), polyvinyl acetate (PVA), polyester (PES), polystyrene (PS), polyethylene terephthalate (PET), and polyurethane (PU), which burn much quicker compared to natural materials like wood [5]. This fast combustion reaction, beside the polymeric structure and additives content (e.g., plasticizers, defoamers, pigments, etc.), significantly promotes generation of toxic compounds, especially PAHs, VOCs and acidic agents when oxygen supply is insufficient for a complete oxidation [4-6]. These toxicants are present in the fire effluent, microscopic particulate pollutants as well as in the post-fire condensates. The human exposure to their mixtures is reported to be linked to adverse health outcomes such as premature mortality, chronic illnesses including lung cancer, asthma and leukaemia, acute inflammation, and cardio-respiratory hospital admissions dependant on the level and number of contacts [7-9]. The repeated exposure of firefighters and emergency response personnel to this cocktail of toxicants, along with other occupational hazards during callouts or training, highlights the importance of their personal protective

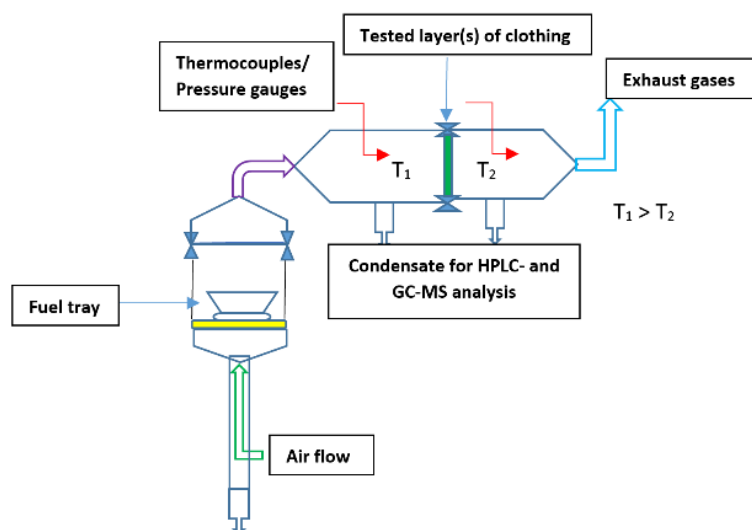
equipment (PPE) providing an efficient and resilient barrier against these toxic chemicals. In 2022, the International Agency for Research on Cancer (IARC) classified firefighters' occupational exposures as carcinogenic to humans [10]. Several recent studies demonstrated that the mortality from cancers and other diseases among firemen are higher compared to the general population [11-14]. Worldwide, firefighters are at higher risk of developing mesothelioma, skin melanoma, bladder and prostate cancers. A recent UK-based study revealed that over 4% of surveyed firefighters have been diagnosed with cancer [15]. Furthermore, the cancer rate for firemen aged 35-39 years was more than 300% higher when compared to the population they serve [15]. During and after firefighting operations, in addition to inhalation and ingestion, the dermal exposure to a variety of toxicants is highly likely, despite firemen donning full PPE [14, 16-18]. Once inside, or in the interior, of the fire suits some toxicants can be adsorbed by the skin, thus significantly contributing to firefighters' overall exposures [17].

The nature and mechanism of toxic chemicals ingress and movement through the firefighters' gear ensembles are not fully understood. The aim of the present work is to identify, with the aid of highly sensitive analytical techniques, the chemical nature of the compounds detected in the fire condensate collected after burning a mixture of solid fuels found in a typical home. Moreover, it evaluates whether the elements of firefighters' turnout gear allow the transport of the toxic chemicals from the fire effluent (the exterior) to the skin protected with a fire suit (the interior). This preliminary study is a part of the extensive experimental programme within the InToxFIRE project (<https://www.intoxfire.net/>), currently on-going at FireSERT and funded by the UL Research Institutes (ULRI), USA.

## 2 EXPERIMENTAL PART

### 2.1 A small-scale experimental set-up

A small experimental set-up, schematically presented in Figure 1, was used to collect and separate out the post-fire condensates containing products of combustion, both water-soluble and soluble in the organic solvent dichloromethane (DCM). Two new (unused) fire suit ensembles, provided by the manufacturer of protective clothing Ardmel Group Ltd. (Scotland, UK), were tested in this study. Each ensemble had three layers, an outer shell, a moisture barrier and a thermal liner (Figure 2). The samples of fire suit ensemble labelled as E<sub>1</sub> contained a fluorinated repellent finish of the moisture barrier, and the samples labelled as E<sub>2</sub> were without this finish.



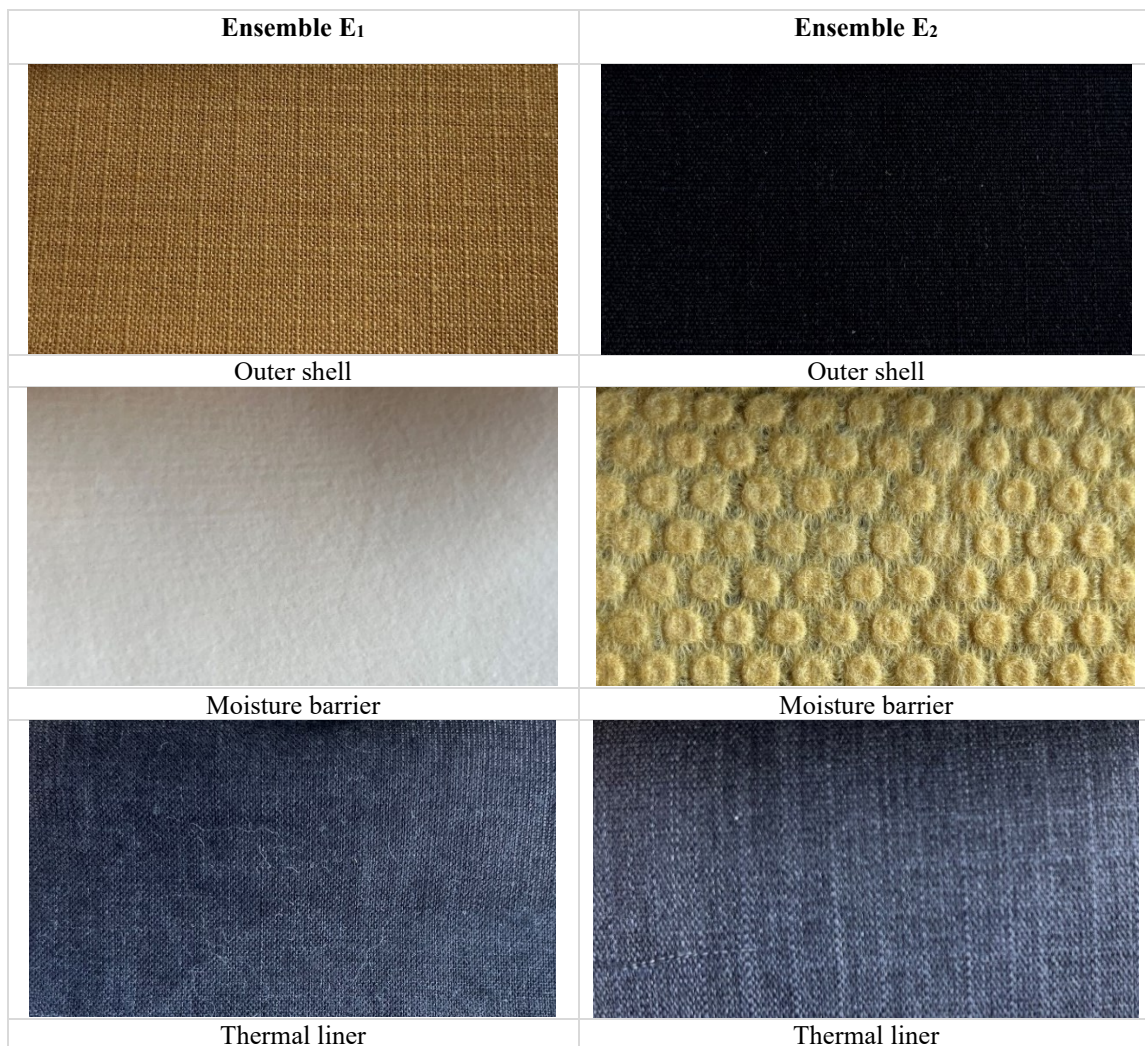
*Figure 1: A small-scale experimental set-up used in the study*

The solid fuel, undergoing smouldering (or flaming combustion, at the start of the experiment) was comprised of different synthetic and natural materials, which could be found in a typical house, as listed below:

- Polyvinyl chloride (PVC, granulated)
- Polyurethane foam (PUR, broken into small pieces)
- Wood shavings

- Cardboard (small squares)
- Polypropylene (PP, granulated)
- Poly(ethylene terephthalate) (PET, small cut pieces from milk bottles)
- Poly(methyl methacrylate) (PMMA, small squares)
- Polystyrene (PS) (small pieces)
- Polyethylene (PE, shredded carrier bags)

To run the experiments, 2 g of each material was weighed and transferred to a ceramic tray, and the tray's content was well-mixed. Then, approximately 2.0 mL of diesel was added dropwise to the mixture to aid ignition, and all the components were mixed again. The tray was placed onto a porous sintered disk of a ceramic funnel (Figure 1). The constant and uniformly distributed stream of air was provided underneath the tray, through the funnel stem using a portable air pump with a narrow nozzle. The top of a flange flask was used to seal the glass funnel with the burning fuel. One neck of this flange top was used to insert a lighter to ignite the fuel. All other necks were properly sealed using stoppers and PTFE membranes. Once the tray's content was ignited, the generated steam and fire effluent were forced into two cylinders, separated by an ensemble, fixed in their conjunction.



**Figure 2: The layers of two ensembles tested in the study**

The sample of a fire suit ensemble 30 mm in diameter, with all the layers in the correct order, was placed securely between two cylinders, each 250 mL in capacity, kept at different temperatures (Figure 1). A continuous stream of air with the constant flow rate (400 L/min), swept the combustion products towards the tested layers of a fire suit ensemble, from the left cylinder, labelled T<sub>1</sub>, to the right cylinder, labelled T<sub>2</sub>. The duration of each experiment was 30 minutes, and the average temperature difference between the cylinders was in the interval from 50 to 54°C. After the completion of the test, the cylinders were allowed to cool down to room temperature.

Then, their walls were washed down with 4× 20 mL of DCM followed by 4× 5 mL of distilled water. The organic and aqueous phases were collected and separated out in a separating funnel. The extracted condensates soluble in DCM were analysed using gas chromatography-mass spectrometry (GC-MS). The high-performance liquid chromatography - high resolution mass spectrometry (HPLC-HRMS) was employed for analysing water-soluble compounds.

## **2.2 Gas Chromatography-Mass Spectrometry (GC-MS)**

The Gas Chromatography-Mass Spectrometry (GC-MS) is suitable for the analysis of mixtures of compounds with relatively low molecular masses (below 800 amu) such as hydrocarbons and other relatively non-polar compounds. An Agilent 7890A GC system linked to a 5975C Inert XL Mass Selective Detector (King's College London) was used in this study. A portion of the DCM mixture (1 µL) was injected into the GC column *via* a heated injection port, which was held at 250-300°C to facilitate vapourisation of the sample. Following volatilisation in the heated injector, the mixture was pushed by a pressurised carrier gas (helium) through the GC column, which was heated in an oven. The GC-MS system was supported with an electron ionization (EI) source. The MS detector operated in the scanning mode, with a scan range of 50 - 500 amu and a threshold of 150 counts at a sampling rate of 22 Hz. The identification of suspected compounds was achieved using the in-house software library "Samples Suspect Screening" based on the specific retention times and mass spectra. All the condensate samples from the organic phase were analysed 3 times each, while the DCM control was analysed 5 times.

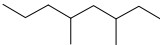


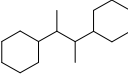
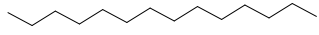
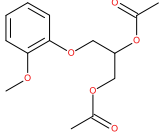
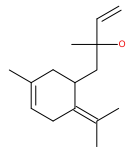
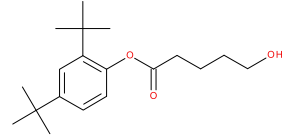
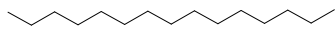
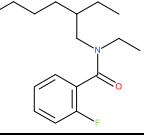
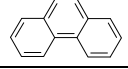
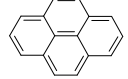

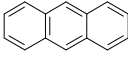
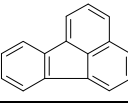
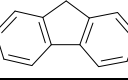
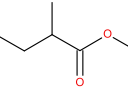
## **2.3 High Performance Liquid Chromatography-Mass Spectrometry (HPLC-HRMS)**

The High-Performance Liquid Chromatography combined with the High-Resolution Mass Spectrometry (HPLC-HRMS) is utilised to detect polar and thermolabile compounds, dissolved in the aqueous phase. In the present study, a Vanquish HPLC (Thermo Scientific) coupled with an Exactive Plus Extended Mass Range (Thermo Scientific), equipped with a heated electrospray ion (HESI) source was used. The samples were injected *via* an LC system into the Atmospheric Pressure Ionisation (API) source. The API provided a soft ionisation, resulting in little or no fragmentation. A typical API spectrum contains only the protonated (positive ion mode) or deprotonated (negative ion mode) molecular ion. The MS spectra provided valuable molecular mass information of single and multiple charged ions and identification of the charge state of each peak in the charge-state envelope of a given compound. An HPLC separation was performed using a C<sub>18</sub> column maintained at 40°C. The mobile phase A contained 0.3% formic acid in water, and mobile phase B contained 0.3% formic acid in acetonitrile. The injection volume was 10 µL, and the flow rate was set to 0.3 mL/min. The total chromatographic time for each test run was 10 min. The standard gradient elution was used based on the laboratory's procedures. Detection was carried out by operating the HESI source in polarity switching mode, with spray voltages of +3.80 kV (in the positive ionization mode) and -3.00 kV (in the negative ionization mode). The auxiliary gas flow rate was 10 arbitrary units, the capillary temperature was 320°C, and the gas heater temperature was 350°C. Data acquisition was conducted at a m/z scan range of 100 to 1000, at resolutions of 70,000 and 35,000 for the positive and negative modes, respectively. The m/z values obtained from HPLC-HRMS were compared with those in the National Institute of Standards and Technology (NIST) monoisotopic mass library to suggest the chemical formulae of the compounds. To ensure that any detected compounds did not originate from the solvents, the samples of DCM and distilled water serving as the controls were also analysed *via* GC-MS and HPLC-HRMS, respectively, at King's Forensics Mass Spectrometry Services (KF-MSS), King's College London. The detection of compounds was considered when peaks had a signal-to-noise ratio of at least 3:1.

## **3 RESULTS AND DISCUSSION**

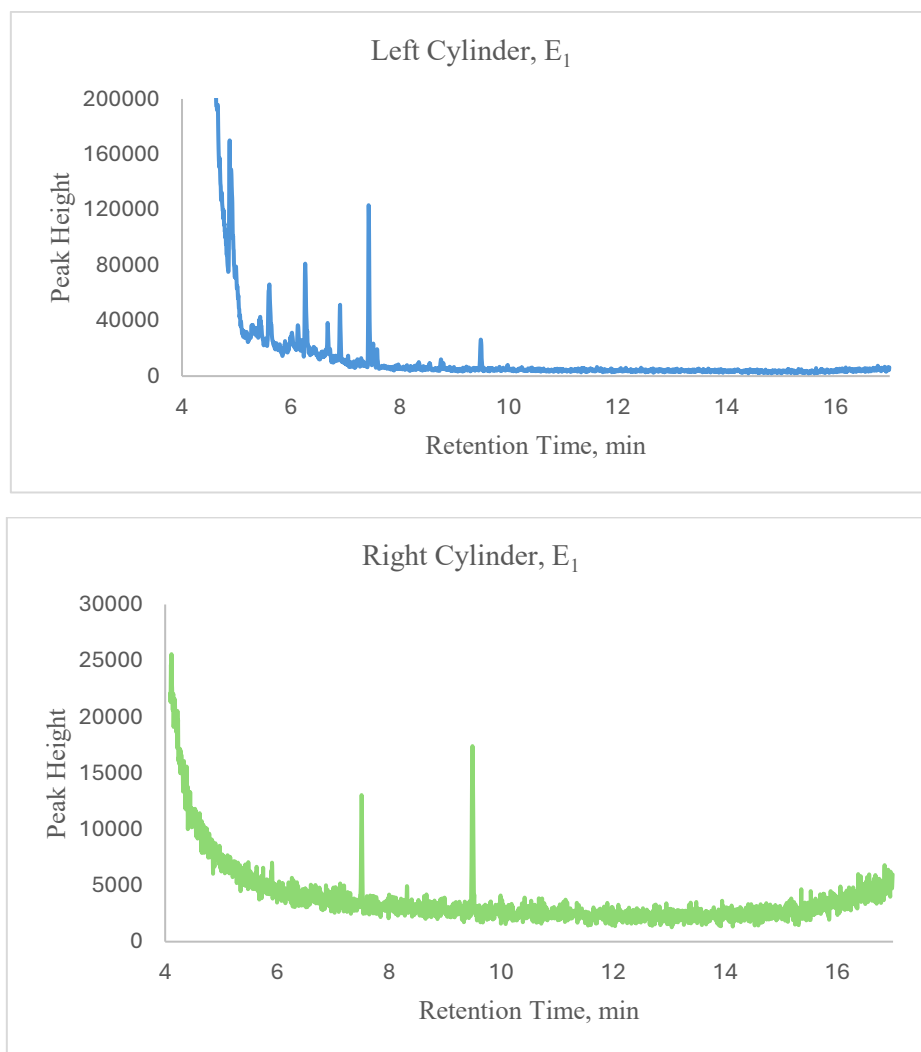
A hazardous mixture containing condensed vapors, liquids, solids, inorganic, organic, polar and non-polar compounds, carcinogens, narcotics, irritants and corrosives was formed in the fire effluent (left cylinder, higher temperature T<sub>1</sub>). Both GC-MS and HPLC-HRMS were used for qualitative analytical purposes to identify the chemical nature of the compounds present in the fire condensates collected from the left cylinder (higher temperature T<sub>1</sub> of 91-96°C) and from the right cylinder (lower temperature T<sub>2</sub> of 41-42°C). It was assumed that one GC peak corresponded to one molecule (or a molecular fragment). Therefore, the number of GC peaks indicated the number of chemical species on both sides of the ensemble in question. The chemical nature of some components of the condensate from the left cylinder is provided in Table 1.

**Table 1: The proposed chemistry of some components of fire condensate collected from the left cylinder**

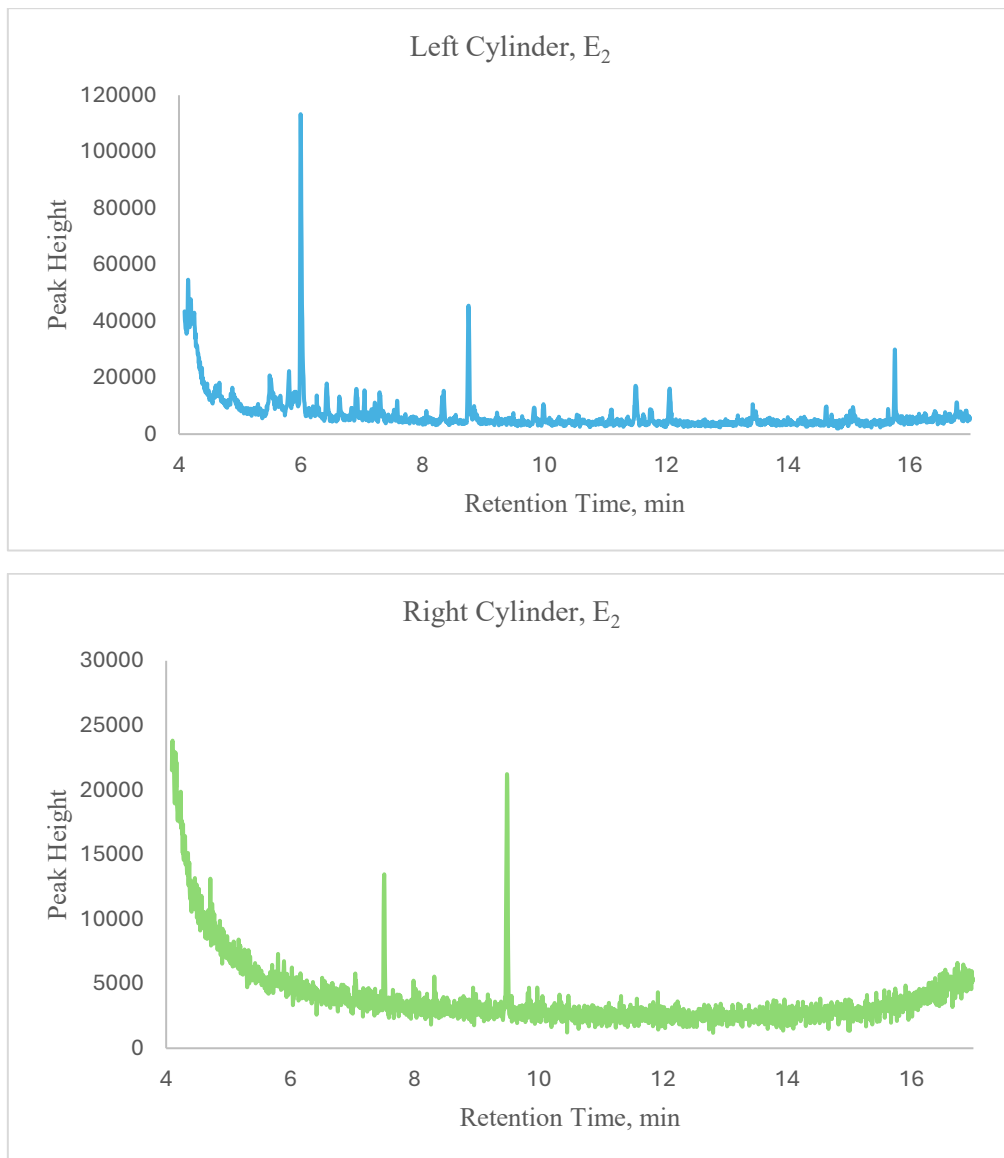
Chemical Name	Chemical Structure	Molecular Formula	Molecular Mass (g/mol)	Occurrence in GC-MS runs	
				E <sub>1</sub>	E <sub>2</sub>
3,5-Dimethyloctane		C <sub>10</sub> H <sub>22</sub>	142.28	2	0
2,2-Dichloroacetaldehyde		C <sub>2</sub> H <sub>2</sub> Cl <sub>2</sub> O	112.94	0	3
4,4-Dipropylheptane		C <sub>13</sub> H <sub>28</sub>	184.36	3	0
2,3-Dicyclohexylbutane		C <sub>16</sub> H <sub>30</sub>	222.41	1	2
Tetradecane		C <sub>14</sub> H <sub>30</sub>	198.39	3	3
1,2-Diacetoxy-3-(2-methoxyphenoxy)propane		C <sub>14</sub> H <sub>18</sub> O <sub>6</sub>	282.29	3	0
2-Methyl-1-[3-methyl-6-(1-methylethylidene)-3-cyclohexen-1-yl]-3-buten-2-ol		C <sub>15</sub> H <sub>24</sub> O	220.35	3	0
2,4-Ditert-butylphenyl 5-hydroxypentanoate		C <sub>19</sub> H <sub>30</sub> O <sub>3</sub>	306.40	0	3
Pentadecane		C <sub>15</sub> H <sub>32</sub>	212.41	3	0
Benzamide, 2-fluoro-N-ethyl-N-2-ethylhexyl-		C <sub>17</sub> H <sub>26</sub> FNO	279.40	3	0
Phenanthrene		C <sub>14</sub> H <sub>10</sub>	178.23	3	3
Pyrene		C <sub>16</sub> H <sub>10</sub>	202.25	0	3
Acenaphthylene		C <sub>12</sub> H <sub>8</sub>	152.19	2	3
Anthracene		C <sub>14</sub> H <sub>10</sub>	178.23	3	3
Fluoranthene		C <sub>16</sub> H <sub>10</sub>	202.25	0	3
Fluorene		C <sub>16</sub> H <sub>10</sub>	166.22	3	3
Methyl 2-methylbutyrate		C <sub>6</sub> H <sub>12</sub> O <sub>2</sub>	116.16	0	3

The identity of suspected toxicants detected by GC-MS in the heated environment varied from aldehydes (dichloroacetaldehyde), long-chain alkanes (3,5-dimethyloctane, tetradecane, pentadecane), esters (2,4-ditert-butylphenyl 5-hydroxypentanoate) to PAHs (phenanthrene, pyrene, acenaphthylene, anthracene, fluoranthene and fluorene). The details of the most potent components, including the chemical names, molecular formulae, chemical structures, molecular masses and their occurrences in GC-MS runs, present in the fire condensate from the left cylinder are provided in Table 1. The occurrence of each chemical in the post-fire condensate from left cylinder varied. For example, 3,5-dichlorooctane was detected in 2 runs when testing the ensemble  $E_1$  and was not detected for the ensemble  $E_2$ . It is important to note that none of the compounds listed in Table 1 were detected in the right cylinder, i.e., the ensembles were effective in inhibiting them from permeation and transfer to the right cylinder.

As it follows from the gas chromatograms shown in Figure 3 and Figure 4, the number of chemical species in the condensates from the right cylinder was significantly reduced by both ensembles. Only two peaks were visible in the chromatogram of the mixture to the right of the ensemble  $E_1$ . Both these compounds were also identified in the control (DCM) and therefore should be ignored. Similar trend was observed for the ensemble  $E_2$ , which effectively suppressed the transport of chemicals to the cooler side. There was a very small peak with retention time of 4.712 min, possibly linked to the presence of 1,4-benzenedicarboxylic acid derivative. More quantitative work is required to confirm the transfer of possibly trace amounts of this compound. Thus, it was found that the toxicants from the warmer cylinder (exterior) did not travel through the layers to the interior of the ensembles.



**Figure 3: A comparison of GC chromatograms of the condensates collected from the left (blue) and right (green) cylinders during testing of ensemble  $E_1$**



**Figure 4:** A comparison of GC chromatograms of the condensates collected from the left (blue) and right (green) cylinders during testing of ensemble E<sub>2</sub>

The screening for suspected toxicants carried out using GC-MS identified a range of carcinogens, or potential carcinogens, including tetradecane, phenanthrene, and pyrene. For example, inhalation, ingestion or dermal adsorption of tetradecane may cause asphyxiation, carcinogenic and even lethal effects (above certain dosage) [19]. Pyrene may cause skin irritation in humans, especially when exposed in the sunlight. It induces mutations in mammalian cells in *in-vitro* assays [20]. Human exposure to phenanthrene can lead to hyperuricemia [21].

The screening for the suspected PAHs was also carried using GC-MS, and the presence of the selected compounds (average values) is given in Figure 5.

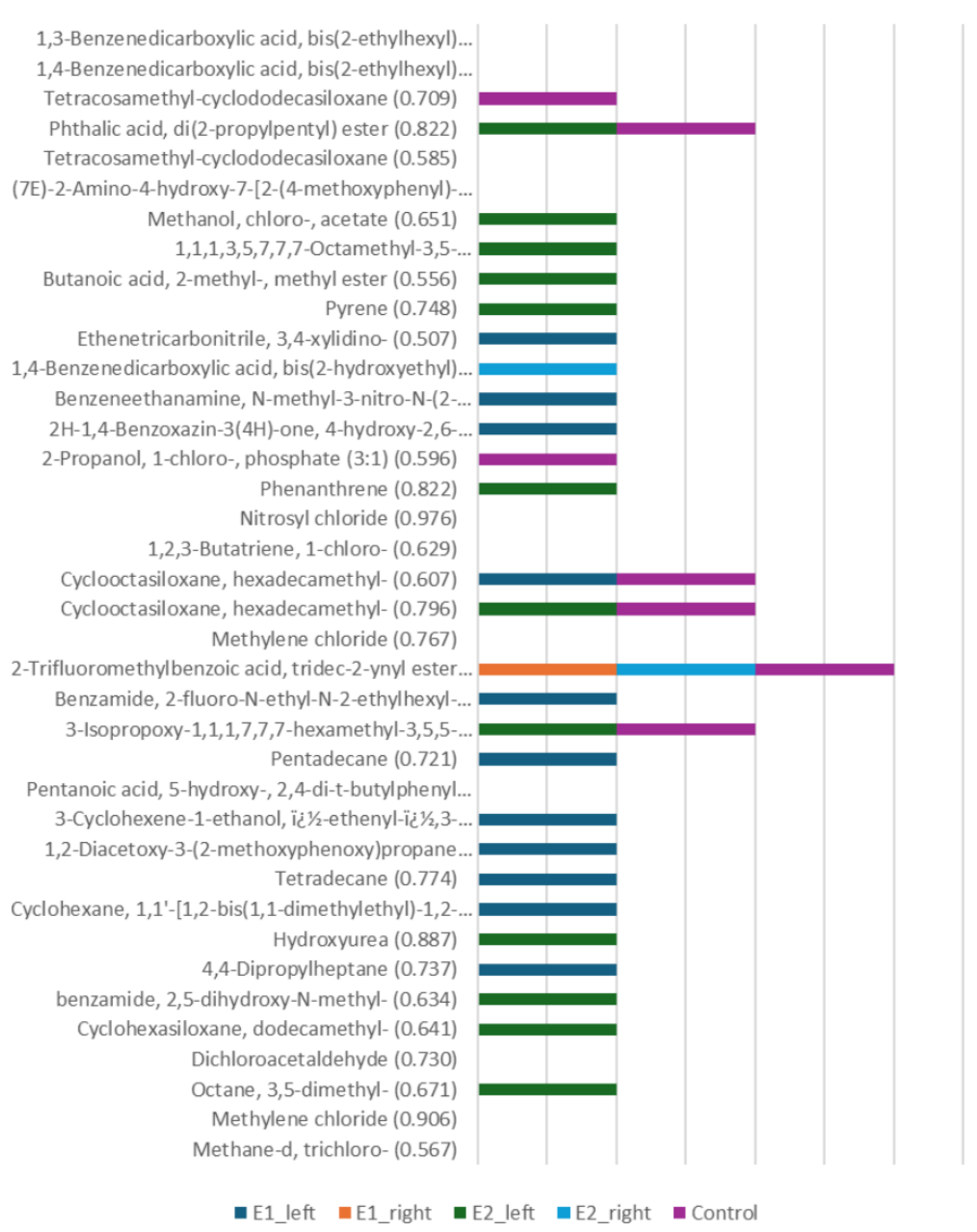


Figure 5: The presence of compounds in the organic phases collected from the left and right cylinders during testing of ensemble E<sub>1</sub> (E1\_left and E1\_right) and ensemble E<sub>2</sub> (E2\_left and E2\_right), and in the control solvent DCM (control)

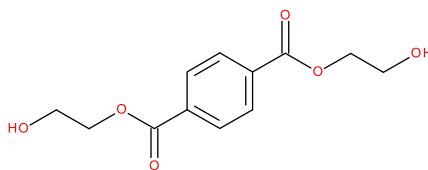
As it follows from Figure 5, there were no suspected compounds to the right of the ensemble E<sub>1</sub>, with the exception of tridec-2-ynyl ester of 2-trifluoromethylbenzoic acid, which was also present in the control (DCM) and therefore was not considered. Thus, the ensemble E<sub>1</sub> prevented the transfer of the following toxicants:

- 4,4-Dipropylheptane
- Cyclohexane, 1,1'-[1,2-bis(1,1-dimethylethyl)-1,2-ethanediy]bis- also known as 2,3-dicyclohexylbutane (see Table 1)
- Tetradecane
- 1,2-Diacetoxy-3-(2-methoxyphenoxy)propane
- 3-Cyclohexene-1-ethanol,  $\alpha$ -ethenyl- $\alpha$ ,3-dimethyl-6-(1-methylethylidene) also known as 2-methyl-1-[3-methyl-6-(1-methylethylidene)-3-cyclohexen-1-yl]-3-buten-2-ol (see Table 1)
- Pentadecane
- 2-Fluoro-N-ethyl-N-2-ethylhexyl-benzamide

- Hexadecamethylcyclooctasiloxane
- 2H-1,4-Benzoxazin-3(4H)-one, 4-hydroxy-2,6-dimethyl
- Benzeneethanamine, N-methyl-3-nitro-N-(2-phenylethyl)
- Ethenetricarbonitrile

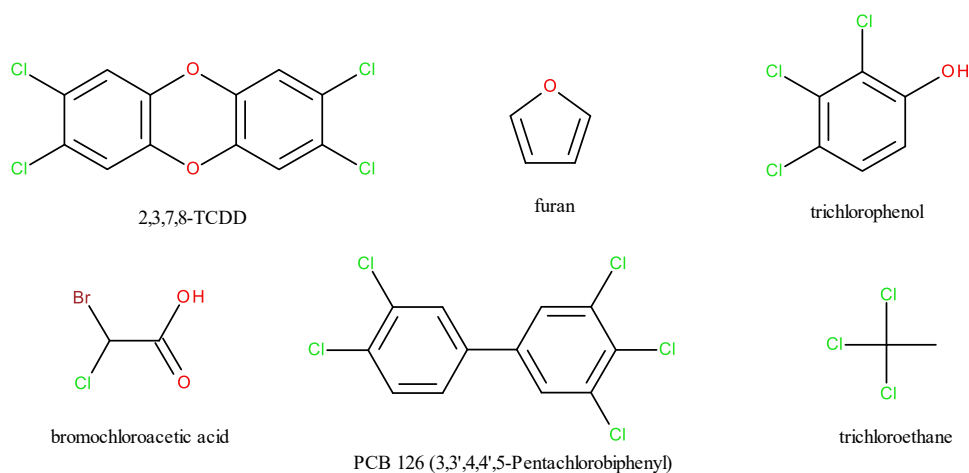
Similarly, it was found that the toxicants from the fire effluent in the left cylinder did not transfer through the layers of the ensemble E<sub>2</sub> to the cooler side. As it follows from Figure 5, only one suspected compound, bis(2-hydroxyethyl) ester of 1,4-benzenedicarboxylic acid, was detected to the interior of the ensemble E<sub>2</sub>. This compound, the structure of which is shown in Figure 6, is generally considered to have a low toxicity and not included in the list of the IARC toxicants [10]. Because 2-trifluoromethylbenzoic acid, tridec-2-ynyl ester, was detected in both in the condensate from the right cylinder and in the control, it was not considered. Other compounds such as phthalic acid, di(2-propylpentyl) ester; cyclooctasiloxane, hexadecamethyl and 3-isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimethylsiloxy)tetrasiloxane were detected both in the condensate from the left and in the control, therefore they were also disregarded. Thus, the layers of the ensemble E<sub>2</sub> did not allow the transfer of the following toxicants:

- 3,5-Dimethyloctane
- Dodecamethylcyclohexasiloxane
- 2,5-Dihydroxy-N-methyl-benzamide
- Hydroxyurea
- Phenanthrene
- Pyrene
- 2-Methylbutanoic acid, methyl ester
- 1,1,1,3,5,7,7-Octamethyl-3,5-bis(trimethylsiloxy)tetrasiloxane
- Chloromethanol acetate



**Figure 6: The chemical structure of bis(2-hydroxyethyl) ester of 1,4-benzenedicarboxylic acid**

The HPLC-HRMS data suggested the presence of a wide range of water-soluble compounds in the fire condensates: over 100 peaks were registered on the chromatograms. They included aromatic derivatives with molecular formula C<sub>7</sub>H<sub>8</sub>O, which may refer to cresols (*o*-, *m*- or *p*-), benzyl alcohol or anisol. The oxygen-bearing compounds such as furans (e.g., C<sub>4</sub>H<sub>4</sub>O), isocyanates (e.g., C<sub>3</sub>Cl<sub>3</sub>NO<sub>2</sub>) and other nitrogen-containing products (e.g., C<sub>8</sub>H<sub>17</sub>N, C<sub>9</sub>H<sub>17</sub>N and C<sub>8</sub>H<sub>19</sub>N) were detected. The chlorinated products such as 1,1,1-trichloroethane, polychlorophenol (C<sub>6</sub>H<sub>3</sub>Cl<sub>3</sub>O), polychlorinated biphenyls (e.g., PCB-126, C<sub>12</sub>H<sub>5</sub>Cl<sub>5</sub>), dioxins (e.g., 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, 2,3,7,8-TCDD) and furans (e.g., tetrachlorodibenzofuran, C<sub>12</sub>H<sub>4</sub>Cl<sub>4</sub>O) were present in the post-fire condensate. The bromine-containing compounds such as bromochloroacetic acid, heptabromodibenzo-*p*-dioxin (molecular formula C<sub>12</sub>HBr<sub>7</sub>O<sub>2</sub>), hexabromodibenzofuran (molecular formula C<sub>12</sub>H<sub>2</sub>Br<sub>6</sub>O) and heptabromodibenzofuran (molecular formula C<sub>12</sub>HBr<sub>7</sub>O) and several PFAS (e.g., CF<sub>4</sub> and C<sub>12</sub>F<sub>26</sub>) were also detected. The HPLC-HRMS data of the condensate from the right cylinder (interior) indicated that carcinogenic and potentially carcinogenic compounds from the IARC list [10] such as PCB-126, furan, 2,3,7,8-TCDD, trichlorophenol, 1,1,1-trichloroethane and bromochloroacetic acid (chemical structures shown in Figure 7) were prevented from the permeation through layers of both ensembles. However, a small number of water-soluble compounds had permeated through the fabric layers: 5 chemical species for the ensemble E<sub>1</sub> and 6 for the ensemble E<sub>2</sub>. The molecular formulae of the compounds that managed to move across the layers were C<sub>6</sub>H<sub>15</sub>NO, ClFO<sub>2</sub>S, HCl<sub>3</sub>Si, and three possible isomers of compound C<sub>4</sub>H<sub>2</sub>Cl<sub>3</sub>N. It is noteworthy that these are the results of the qualitative analysis. A quantitative study involving analytical methods development is required and is currently ongoing.



**Figure 7: Chemical structures of carcinogenic and potentially carcinogenic compounds**

## 4 LIMITATIONS

There are some limitations in the experimental set-up used in this preliminary work. A more accurate temperature control of both cylinders is required. It would be useful to carry out testing on a medium scale by placing the ensemble between two tube furnaces, the temperature of which can be set and automatically controlled. This preliminary qualitative study considered a limited number of toxicants. It is very important to evaluate the concentration levels of the toxicants on both sides of the ensembles. It would be useful to focus the study on some specific compounds (e.g., pyrene, furan, anthracene, etc.) or the groups of compounds (PAHs, VOCs, PFAS etc.). The moisture content was not simulated/measured in the small experimental set-up. It will be beneficial to carry out testing of fire suit ensembles, placed on mannequins in real-life fire situations. It is recommended to take swabs, for GC- or LC-MS, from different locations on the exterior and interior of fire suits, before and after real life fire-fighting situation. Finally, it would be useful to test already used and laundered ensembles of fire suits to estimate the possible influence of decontamination processes on protective performance of fire suits, as planned in the experimental programme of the InToxFIRE project.

## 5 CONCLUSIONS

- The screening for suspected toxicants, with the aid of GC-MS and HPLC-HRMS, identified a range of carcinogens and potential carcinogens including tetradecane, phenanthrene, pyrene, polychlorinated biphenyl (PCB)-126, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), 1,1,1-trichloroethane, polychlorophenol and bromochloroacetic acid formed in the post-fire condensate. Other compounds such as isocyanates, acenaphthylene, anthracene, fluorene, etc. were also detected in the fire condensates. Both tested ensembles were effective in preventing the permeation of these toxicants.
- It was also found that both unused ensembles E<sub>1</sub> and E<sub>2</sub> did not allow the transfer of PAHs across the layers of fire suits, which is a positive outcome of the small-scale testing. The compounds classified by the IARC as carcinogenic or potentially carcinogenic to humans, were not found in the condensates collected from the right cylinder. As for the water-soluble compounds, both E<sub>1</sub> and E<sub>2</sub> ensembles exhibited a good degree of protection. However, the resistance against the permeation of these compounds by the E<sub>2</sub> ensemble was slightly lower than E<sub>1</sub>, possibly due to the lack of polyfluorinated finish of the moisture barrier.

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