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Assessment of dermal hazard from acid burns with fire retardant garments in a full-size simulation of an engulfment flash fire

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ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form
11 April 2016
Accepted 14 April 2016

Keywords:
Fire resistance textiles
Modacrylic
Combustion
Acid burns
Toxicology
Risk assessment

ABSTRACT

There have been concerns that fire-derived acid gases could aggravate thermal burns for individuals wearing synthetic flame retardant garments. A comparative risk assessment was performed on three commercial flame retardant materials with regard to relative hazards associated with acidic combustion gases to skin during a full engulfment flash fire event. The tests were performed in accordance with ASTM F1930 and ISO 13506: Standard Test Method for Evaluation of Flame Resistant Clothing for Protection against Fire Simulations Using an Instrumented Manikin. Three fire retardant textiles were tested: an FR treated cotton/nylon blend, a low Protex® modacrylic blend, and a medium Protex® modacrylic blend. The materials, in the form of whole body coveralls, were subjected to propane-fired flash conditions of 84 kW/m^2 in a full sized simulator for a duration of either 3 or 4 s. Ion traps consisting of wetted sodium carbonate-impregnated cellulose in Teflon holders were placed on the chest and back both above and under the standard undergarments. The ion traps remained in position from the time of ignition until 5 min post ignition. Results indicated that acid deposition did increase with modacrylic content from 0.9 μmol/cm^2 for the cotton/nylon, to 12 μmol/cm^2 for the medium modacrylic blend. The source of the acidity was dominated by hydrogen chloride. Discoloration was inversely proportional to the amount of acid collected on the traps. A risk assessment was performed on the potential adverse impact of acid gases on both the skin and open wounds. The results indicated that the deposition and dissolution of the acid gases in surficial fluid media (perspiration and blood plasma) resulted in an increase in acidity, but not sufficient to induce irritation/skin corrosion or to cause necrosis in open third degree burns.

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http://dx.doi.org/10.1016/j.burns.2016.04.012

1. Introduction

Concern has been voiced in the fire protection industry that protective textiles composed of synthetic fibers may represent a health hazard as the result of the gaseous acidic combustion products. Several bench top studies have looked at combustion gas generation from small areas of textiles and have reported the generation of hydrogen chloride, hydrogen cyanide, nitric oxides, hydrogen sulfur oxides, and other combustion constituents coming from flame retardant products containing Protex® modacrylic and nylon fibers [1,2]. A recent real-time analysis of gases generated during the full size engulfment simulations reported that synthetic flame retardant materials produced high concentrations of hydrogen chloride and cyanide with nominal amounts of nitrogen oxides and sulfur oxides [3]. However, this was not an issue as a toxicological inhalation hazard, because of the very high temperature and short duration of production [4]. Concerns remained that while the acidic gases may not represent an inhalation hazard, the ability of the gases to get trapped under the garments for prolonged periods of time might represent a hazard of dermal acid burns. Ackermann et al. [5] recently undertook a study where they concluded that acid deposition would certainly increase the severity of any burn received. Unfortunately, the authors did not directly examine the physiological implications of acid vapor exposure to substantiate their conclusion.

The purpose of this study was to address the issue as to whether acidic gaseous combustion products represent a potential dermal hazard to individuals exposed to a flash fire event. Using a full-sized simulator, three types of commercial fire retardant garments as full coveralls were exposed to propane-fired flash conditions of 84 kW/m^2 for either 3 or 4 s. Support manikins were fitted with sodium carbonate-impregnated cellulose ion traps to mimic skin deposition of dissociated acids. The results were used to determine both exposure and probability of adverse dermal injury to an individual who endures such an event.

2. Materials and methods

2.1. Experimental design and measurement systems

Three fire retardant garments were tested for gas emissions in a full sized flash simulation. Materials were in the form of standardized work coveralls. The garments tested were all commercially available and identified as follows:

- FR Cotton: Blended 88/12 Proban CC™ cotton blended with nylon
- Med. Modacrylic: A medium content blend containing Protex® modacrylic
- Low Modacrylic: A low content blend containing Protex® modacrylic

The ion traps consisted of 90 mm Watman #41 filter papers soaked in a solution of 1 M sodium carbonate (pH 10.3) for 12 h and then dried at room temperature under ultrapure nitrogen for 6 h. The individual filters were placed in clean individual 100 mm petri dishes for storage before use.

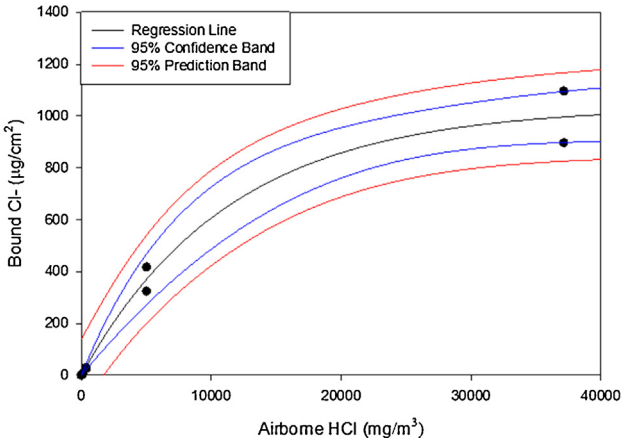

Fig. 1 – Ion trap calibration. Responsiveness of precision of the ion traps was determined by placing the ion traps in a controlled atmosphere of hydrogen chloride for 5 min.

The capacity of the ion traps was tested using a chamber of known atmospheric concentrations of hydrogen chloride. The ion traps were exposed to known concentrations for 5 min and then analyzed for chloride content. The relation showed an exponential rise to maximum (r^2 = 0.983) that was linear with the range of results attained in this study (Fig. 1).

The garments were pre-conditioned as required and then exposed to a simulated engulfment flash fire consistent with the requirements of ASTM F1930 [6]. As required, the manikin was dressed in 100% cotton t-shirt and briefs under the test work garment. Prior to testing, the ion traps were removed from the petri dishes, placed in clean Teflon holders, and wetted with deionized water. The holders were then affixed to the test manikin on the front and back of the trunk with one on the inside of the under garments, one on the outside (four total per test; Fig. 2). The traps outside of the underwear were intended to represent skin areas directly adjacent to the test garments. Two field blanks were included in the testing regime.

The full size fire exposure was performed in a 4.34 m by 3.78 m by 2.45 m high enclosure. The heat flux was provided by propane-fired jets with 12 burners on six stands. The system was calibrated to provide an average thermal input of 84 kW/m^2 (Table 1) and met the required standards of ASTM F1930-13.

Table 1 – Radiant energy calibration for the manikin used in the ASTM F1930 fire exposures.

Location group	No. of sensors	Mean	Minimum	Maximum	Std dev.
		Cal/cm^2			
Head	8	2.079	1.384	2.799	0.428
Left arm	10	1.935	1.416	2.232	0.262
Right arm	10	2.042	1.605	2.477	0.296
Left leg	22	1.979	1.687	2.228	0.136
Right leg	22	1.956	1.579	2.278	0.159
Chest and abdomen	28	2.063	1.593	2.509	0.251
Back	22	1.988	1.639	2.465	0.201