Experimental Investigations of the Protection Capabilities of Novel Chemical Protective Substrates

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ABSTRACT

In the current times of threats and terror, highly efficient chemical protective suits and chemical decontamination wipes are necessary. Therefore, it is of extreme necessity to develop high precision analytical methods to quantify the protective capabilities of chemical protective substrates. In this study a neoteric protocol has been devised to characterize the adsorption of toxic chemicals using a Thermo-gravimetric analyzer.

Activated carbon fabrics (ACF) which are made out of activated carbon fibers are highly efficient in removing toxic chemicals from gas streams via adsorption. However, direct contact of activated carbon with skin is not recommended because of its toxic nature. Hence, structurally well integrated**,** three layered fabric material with the activated carbon fabric layer sandwiched between two skin friendly non-woven fabric layers was manufactured using *H1 technology needle loom Fehrer®AG.* Nonwoven activated carbon felt (ACN) was used as the middle adsorbent layer and the next-to-skin layers were made out of cotton fibers. A quantitative comparative study has been carried out to objectively quantify the protection characteristics of these novel protective composites.

The results indicate that the Thermo-gravimetric analyzer (*Pyris 1 TGA® Perkin Elmer™*), which is conventionally used for chemical composition analysis and oxidation behavior, when used in this setting, is an efficient analytical tool for quantifying the adsorption characteristics such as the rate of adsorption, saturation time and adsorption capacity. The work reported in this paper is timely and contributes to our homeland security and national defense.

INTRODUCTION

Since the events of September 11, 2001 decontamination of chemical and biological agents has become a priority issue worldwide. Decontamination of chemical warfare agents is not only required on the battle field but also in laboratory, pilot plants, production and destruction sites. Most of the research is focused on battlefield removal of agents which require instantaneous decontamination by both physical and chemicals means.

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A neoteric protocol to characterize the adsorption of toxic chemicals using a Thermo-gravimetric analyzer (TGA) has been established in our study. The TGA provides a sophisticated mechanism to maintain a controlled environment around the activated carbon sample via the temperature controlled furnace throughout the duration of the experiment. The experimental design has been developed to best utilize the Thermogravimetric analyzer (TGA), which is conventionally used for chemical composition analysis and oxidation behavior, as a tool to record the complete adsorption phenomenon of chemical vapors on fabric samples. TGA, along with data collection software (*Pyris Manager ®)* was able to precisely determine various adsorption/protection parameters such as: 1) Rate of adsorption; 2) Saturation time; 3) Adsorption capacity and 4) Percentage weight gain at various time intervals. Appropriate protocol and guidelines regarding the proper use of the TGA instrument have been developed to achieve precision and accuracy.

Nonwoven Activated Carbon Materials:

ACN "ACN-K" sample was novoloid (phenolic) precursor activated carbon nonwoven fabrics from a well established supplier. The "ACN-W" was purchased from another source. The "ACN-G" was purchased later from an overseas supplier. The purchase costs for all the three carbons differed significantly. Details of these precursor fabrics are shown in Table I

Table I. NONWOVEN ACTIVATED CARBON FABRICS (ACN)

ACN - type	Weight* (g/m^2)	Woven structure	Specific Surface Area (m^2/g)*	Precursor Material
ACN-W	134.33 (5.92)	Nonwoven	1366	Polypropylene
ACN-K	136.11 (10.65)	Nonwoven	1500	Phenolic Carbon
ACN-G	182.17 (4.92)	Nonwoven	1196	Viscose Rayon

*Weight of ACN-W was based on 3 repeats, ACN-K was based on 8 repeats and ACN-G was based on 5 repeats. Values within parenthesis Indicate standard deviation values.

Composite Details:

For the manufacturing of the composite, the nonwoven activated carbon fabric (ACN - here denoted as L_2 - Fig 1) was placed between the two nonwoven cotton fabric layers L_1 & L_3, manually. The base substrate fabrics (denoted as L1 and L3 in Fig 1.) constitute the top and the bottom layers of the three layered composite protective fabric, whereas the ACN (denoted as L_2 in Fig 1.) forms the middle adsorbent layer. This arrangement of ACN sandwiched between two non-woven fabric webs was passed through the H1 technology feeding line and the 3 layered structure was needle punched at very high speed. This process results in fiber entanglement between the non-woven cotton fabrics L_1, L_3 and the ACN fabric (L_2). Thus the final product was a structurally, well integrated**,** three layered fabric material with the ACN layer covered by two non-woven cotton layers. A pictorial representation of the three layered composite cross section is shown in Figure 1.

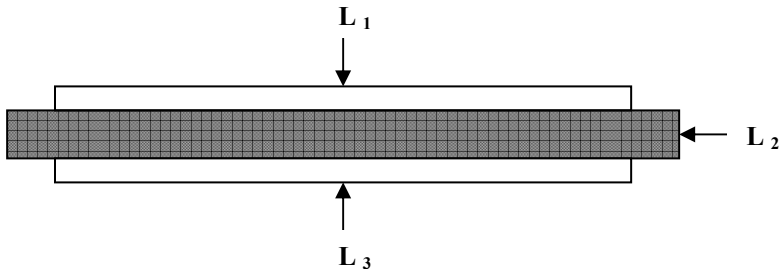

Figure 1. The structure of three layered composite protective fabric (CC1)

where,

L 1 = Non-woven cotton fabric.
L 2 = Nonwoven activated carbon fabric.
L 3 = Non-woven cotton fabric.

Table II. ADSORPTION DATA FOR NONWOVEN ACTIVATED CARBON FABRICS & M 291 Kit

Substrate	Structure	Specific Surface Area (m^2/g)*	Precursor Material	Adsorption* Capacity (g/g)
ACN W	Nonwoven	1366	Polypropylene	0.1382 (0.0027)
ACN K	Nonwoven	1500	Phenolic Carbon	0.1802 (0.0127)
ACN G	Nonwoven	1196	Viscose Rayon	0.1551 (0.0039)
CC 1	Nonwoven	1500 precursor	Phenolic Carbon	0.0732 (0.0062)
M 291	Powder	N/A	N/A	0.0662 (0.0044)

* Adsorption Capacity Data for ACN-W carbon were based on 7 repeats, ACN-K and ACN-G are based on 6 repeats, CC on 7 repeats and M 291 on 6 repeats.* Values within parenthesis Indicate standard deviation values.

RESULTS & DISCUSSION

All the statistical test are run considering the four data sets (M 291 Kit, CC1, ACN K, ACN W and ACN G) together to minimize the errors. We used Tukey-Kramer HSD test for pair-wise comparison of the means.

Adsorption capacity:

The results indicate much lower adsorption capacities (0.059 – 0.071 g/g) for the M291 carbon samples as compared to (0.133 – 0.196 g/g) observed in case of any of the three other activated carbon fabrics discussed earlier. It is obvious from the results that the adsorption capacity of the M291 Kit is significantly lower than the three non-particulate activated carbon nonwoven fabrics under consideration. We further verify this by statistical analysis.

Cotton Composite:

The results demonstrate the adsorption capacities of the composite layer, the M291 Kit and the middle ACN layer of the three layered composite. The results indicate much lower adsorption capacity (0.066 ± 0.004 g/g) for the M291 carbon samples as compared to (0.16 ± 0.016 g/g) observed in case of the separated middle adsorbent layer of the three layered composite.

CONCLUSIONS

Results obtained in the study were extremely promising indicating that all three precursor materials (ACN-W, ACN-K and ACN-G) turned out to be an excellent substrates for their use as potential decontamination wipe for toxic chemicals such as PMP in its solution form. The study has shown that the non-woven multilayered composite offer a good prospects to be used as a chemical warfare decontamination wipe. The Thermo-gravimetric analyzer can function as a high precision balance in addition to providing isothermal conditions and controlled flow rates of gases. Hence, the thermo-gravimetric analyzer is a excellent analytical tool for quantifying the adsorption characteristics of various substrates. Based on visual examination it is evident that the nonwoven activated carbon materials are *devoid of loose particles* and hence carry a high potential to effectively decontaminate open wounds and sensitive parts of military equipments. Such nonparticulate materials can also serve as inner layer for a chemical and biological protective suit.

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