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DEVELOPMENT AND EVALUATION OF SELECTIVELY PERMEABLE MEMBRANES FOR LIGHTWEIGHT CHEMICAL BIOLOGICAL PROTECTIVE CLOTHING

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1. Abstract

Selectively permeable membranes are widely used throughout the chemical industry for carrying out chemical separations. Work is underway to develop membranes for novel use in lightweight, chemical biological (CB) protective clothing. Membranes, which function without the use of a carbon adsorbent medium, have been developed and evaluated. Mechanical properties, barrier properties, and moisture vapor transmission rates have been determined. Prototype garments have been fabricated, and limited field evaluations have been accomplished. Subjective comfort and durability have been determined.

2. Introduction

CB protective clothing has been developed and improved over the years for industrial, medical, and military uses. The threat of exposure to hazardous chemicals and biological agents remains very real, and the need for proper protection is as important today as it ever has been. The materials that have been used to provide protection range across a spectrum from air-impermeable materials to air-permeable materials combined with activated charcoal. Elastomers, plastic films, and multilayer film/fabric composites such as butyl rubber coated fabrics are used in gloves, boots, respirators, and OSHA Level A, fully encapsulating suits, and provide excellent protection, but the clothing utilizing these air-impermeable materials is heavy, uncomfortable, restrictive, and can result in the rapid onset of heat stress.[1] Air-permeable materials combined with activated charcoal such as those used in the US Army Battle-Dress Overgarment (BDO) [MIL-S-43926] and the US Marine Corps Saratoga Overgarment (Saratoga®) [MIL-S-29461], are more comfortable than their air-impermeable counterparts, but have the same limitations to a lesser degree. These undesirable characteristics also pose a logistics burden to the users. These garments differ in their protective materials, shell and liner fabrics, garment designs, and interfaces/closures (e.g., between gloves and jacket sleeves). Both garments are designed to provide the user with protection from hazardous chemicals, toxins, and deadly microscopic organisms employed as CB warfare agents.

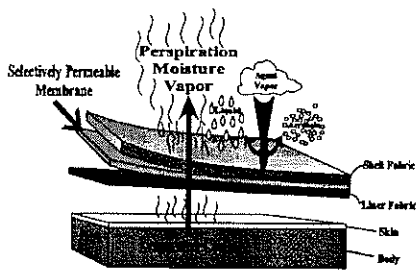

Figure 1. Material Concept

This work was undertaken to develop a new generation of materials for lightweight, CB clothing based on the use of selectively permeable membranes (Figure 1). Membranes have been used worldwide by the chemical industry for carrying out gas separations, in the purification of water by reverse osmosis, and in medical applications.[2,3] Microporous membranes are used today in rainwear and in cold-weather clothing because they serve as barriers to liquid water while still allowing moisture vapor transport through the clothing, providing relief from heat stress through evaporative cooling. In this work membranes have been developed which serve as barriers to hazardous chemicals and agents of biological origin (toxins, bacteria, and viruses) while still allowing a significant rate of moisture vapor transport.

The different types of materials used for CB protective clothing are illustrated in Figure 2 and include permeable, semipermeable, impermeable, and selectively permeable fabrics.

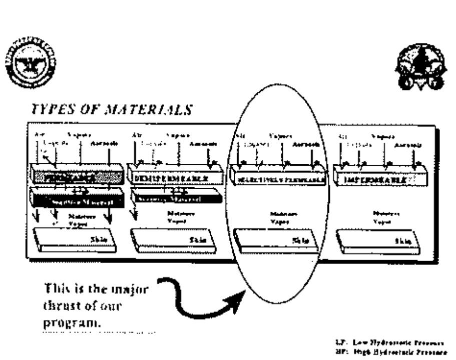

Figure 2. Different Types of Materials

Permeable fabrics usually consist of a woven shell fabric, a layer of sorptive material such as an activated carbon impregnated foam or a nonwoven felt, and a liner fabric. Since the woven shell fabric is not only permeable to air, liquids, and aerosols, but also vapors, a sorptive material is required to adsorb toxic chemical vapors. Since liquids can easily penetrate permeable materials, functional finishes such as Quarpel® and other fluoropolymer coatings are usually applied to the outer-shell fabric to provide liquid repellency. Permeable clothing allows convective flow of air thus allowing the body to cool itself through evaporative cooling.

Semipermeable materials such as a Gore-Tex® membrane allow moisture vapor to be transmitted through the material thus effectively reducing the heat build-up in the protective garment, and at the same time preventing liquid and aerosol penetration. Although this is an improvement over permeable fabrics, toxic chemical vapors can permeate through semipermeable materials, therefore, as with permeable fabrics, the use of a sorptive material is required for adsorption of toxic chemical vapors.

Impermeable materials such as butyl rubber, neoprene, and other elastomers have been commonly used over the years to provide CB agent protection.[1] These types of materials, while providing excellent barriers to penetration of CB agents in liquid, vapor, and aerosol forms, impede the transmission of moisture vapor (sweat) from the body to the environment. Prolonged use of impermeable protective clothing, especially in the warm/hot climates of tropical areas, significantly increases the danger of heat stress. Likewise, hypothermia will likely occur if they are used in the colder climates.

Based on these limitations, a microclimate cooling and heating system is sometimes used as an integral part of some impermeable protective clothing systems. The US Army Improved Toxicological Agent Protective (ITAP) suit is an example of an impermeable clothing system.

Selectively permeable materials combine the properties of impermeable and semipermeable materials. They serve as barriers to hazardous chemical vapors while allowing the transport of moisture vapor. The protection mechanism of selectively permeable fabrics is based on a selective solution/diffusion process, whereas carbon-based fabrics rely on the adsorption process of the activated carbon media.

Selectively permeable materials represent a new concept in CB protective clothing. They are nonporous solution-diffusion membranes[3], where a permeant dissolves into the membrane, diffuses across it, and desorbs on the other side based on concentration gradient, time, and membrane thickness (Figure 1). Therefore, unlike semipermeable materials, selectively permeable materials act as a barrier to chemical vapors without the use of a separate layer of sorptive material such as activated carbon for adsorption of toxic chemicals.

3. Experimental

Numerous candidate membranes were obtained from industry or developed with industrial partners. Membranes were characterized for their physical properties using standard methods. Chemical barrier properties and moisture vapor transmission properties were determined using in-house methods. Two membrane systems found to exhibit outstanding properties are a polyallylamine-based membrane developed by W.L. Gore and Associates, Inc. and a cellulose-based membrane developed with Acordis Research.

4. Results and Discussion

The membrane/fabric systems from Gore and Acordis were found to have acceptable physical properties and weigh about half that of the BDO and the Saratoga® fabric systems. Permeation of water and selected organic vapors through Gore and Acordis fabric systems showed that they are highly permeable to water vapor but not to common organic vapor molecules (Figure 3). The membranes are considered to be waterproof because of their excellent hydrostatic resistance (Figure 4). In order to determine evaporative cooling potential, candidate membrane/fabric swatches were tested on a standard sweating guarded hot plate, and they were found to have lower intrinsic thermal resistance and a lower intrinsic water vapor resistance than any of the fabric systems currently in use in military CB clothing systems (Figure 5).

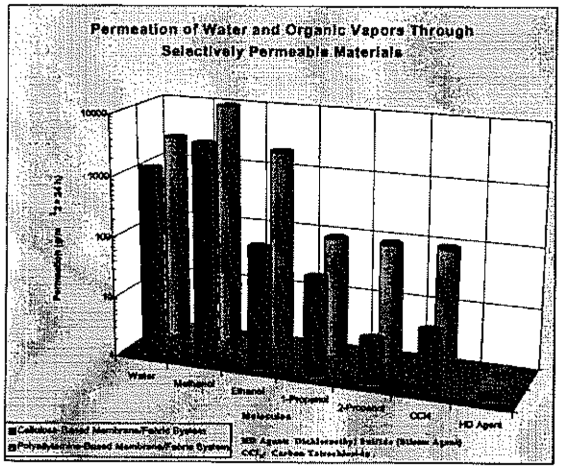

Figure 3. Permselectivity

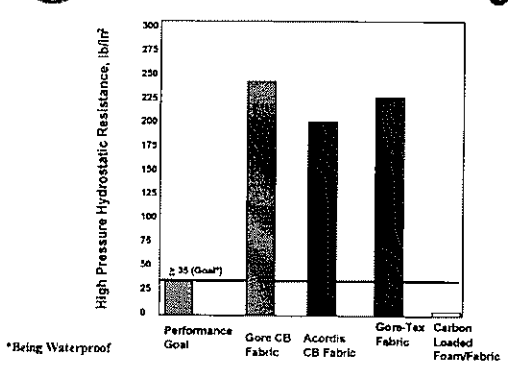

Figure 4. Hydrostatic Resistance of Candidate CB Fabrics

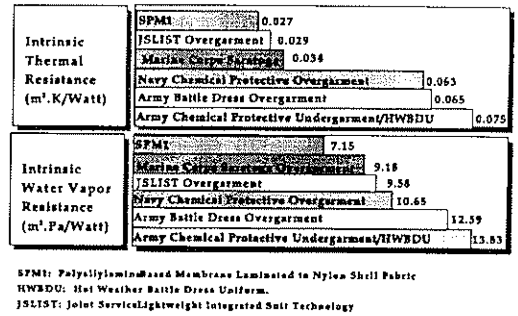

Figure 5. Evaporative Cooling Potentials (Guarded Hot Plate, ISO 11092)

Moisture vapor transmission was determined using a novel dynamic moisture permeation cell developed in-house.[5] Candidate membranes showed very good MVT properties across a wide range of relative humidity as compared to an impermeable film. MVT was also measured using the standard method (ASTM E96-95, Method B), and these tests indicated that the Gore membrane has slightly higher MVT than a semipermeable fabric, but lower than that of a "breathable" carbon-based fabric system and much better than an impermeable fabric system.

Barrier properties against a variety of liquid and vapor chemical challenges were determined using in-house permeation test methods.[6,7] In general, membranes having good MVT properties were not good barriers to chemicals. The Gore and Acordis membranes were found to be exceptions in that they exhibited very good barrier properties to a battery of chemicals while still having high MVT properties. Live agent testing using standard protocols indicated excellent barrier properties to chemical agents. The membrane/fabric systems were fabricated into prototype jackets and trousers and subjected to wear tests with favorable results (Figure 6). It is expected that rigorous field evaluation of these garments will be accomplished in the near future. Test subjects preferred these garments to the BDO, Saratoga®, and JSLIST overgarments which were used as standards in the field tests. The users perceived the membrane/fabric prototypes as being lighter weight and more comfortable.

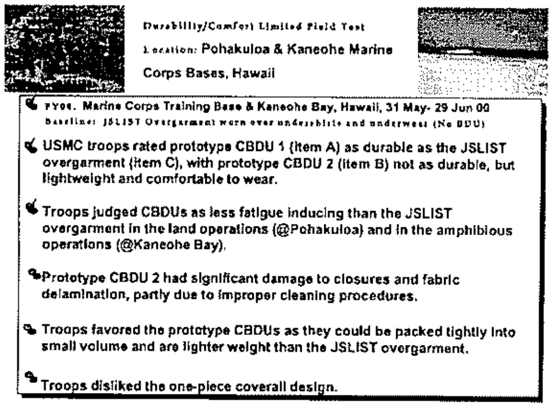

Figure 6. Highlights of May/June 2000 Field Exercise

5. Conclusions

Permselective membranes have been developed which serve as excellent barriers to hazardous chemicals and biologicals while allowing moisture vapor transport to occur. It is expected that this novel approach to CB clothing will lead to a dramatic increase in comfort and reduced heat stress in military overgarments as well as the emergence of a CB duty uniform. It is also anticipated that these novel garments will prove useful to individuals involved in emergency response to chemical and biological incidents such as police, firefighters, and emergency medical personnel. Garments fabricated from the novel materials are lightweight, compared with standard in-use garments because they contain no carbon and yet provide protection against chemical and biological warfare agents in liquid, vapor, and aerosol forms. Effective closures and interfaces between the clothing items such as boots, gloves, and gas masks are required, and novel closure systems have been developed and incorporated into the prototypes. Limited field assessments indicated preferences over current CB protective garments that are carbon-based, however, extensive field evaluations will be required to ensure user acceptance and field durability. Selectively permeable fabrics have excellent dual use potential in CB/environmental protective clothing for emergency responders, pesticide, industrial chemical handlers, medical personnel, and environmental clean-up personnel.

6. References

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