Breaking with tradition

Chemical/biological (CB) protective clothing has advanced over the years to provide excellent protection to war-fighters facing the threat of CB warfare agents. This threat remains an active concern because of the relative ease with which such weapons can be acquired, at least on a small scale. Furthermore, the increasing concern over terrorism means the threat is not limited to the military, but is also a concern in civilian sectors. The Tokyo subway incident of 1995 involving Sarin nerve agent brought this reality home to the Japanese and the rest of the world. In addition to traditional military chemicals, there are concerns with regard to toxic industrial chemicals. It is therefore necessary to ensure that civilian emergency responders such as police, firefighters, and emergency medical technicians are provided with appropriate CB clothing.

Items of CB protective clothing are fabricated from a spectrum of materials that cover a variety of properties, ranging from materials which are air-impermeable to those which have significant air permeability. CB protective clothing used by the military has for many years been based on the use of activated carbon incorporated in some manner into an air-permeable textile system. The activated carbon is contained within the textile system, acts as a universal adsorbent, and is protected from contact with liquid droplets by a liquid-repellent outer shell fabric. Such textile systems are considered to be relatively comfortable because of their "breathability." In general, the highest level of protection is achieved by utilising air-impermeable materials in the form of a fully-encapsulated ensemble. Such clothing systems, sometimes referred to as Occupational Safety and Health Act (OSHA) Level A, provide excellent protection from chemical vapours, liquids, aerosols, and biological agents. These fully encapsulated ensembles are very costly, and they strictly limit the mobility of the wearer.

Breathe easy

While most of these CB clothing systems provide excellent protection, the clothing remains heavy and bulky. The clothing may also subject the wearer to heat stress under conditions of mild exertion. One approach to the development of lighter weight and more comfortable CB clothing involves the use of membranes. Membranes have found applications in specialty clothing for civilian applications such as rainwear and sports clothing. The attractiveness of membranes for these applications is based in part on the fact that they're very thin and are therefore very lightweight. The membranes used in these civilian applications are microporous. As such, they allow moisture vapour transport to occur through the membrane while being liquid repellent. Hence the wearer is kept dry from the rain while being comfortable through the sweat management allowed by the membrane. Since these types of membranes allow vapours to pass, they are not suitable for use in CB clothing unless a layer of carbon is added to back up the membrane.

In order to reduce the weight of CB clothing by a significant amount, it is necessary to eliminate or at least reduce the amount of carbon in the traditional garments. Membranes can be used to accomplish this weight reduction. Air-impermeable membranes may also be impermeable to hazardous chemicals provided the proper polymer is selected. The membrane serves as a barrier by blocking the absorption of the challenge chemical into the surface and limiting the diffusion of the chemical across the membrane. To maximise comfort in such a clothing system, a degree of sweat management is necessary. The clothing system, and therefore the membrane, must allow a degree of moisture vapour transport through the membrane so that there can be a measure of relief from heat stress through evaporative cooling. The concept is illustrated in Figure 1. Membranes have now been developed specifically for the application of CB clothing. These materials have been thoroughly characterised for their physical and barrier properties. Several of these membranes have been fabricated into prototype garments, and some of these garments have been extensively evaluated in field tests. Subjective comfort has been determined, and the garments have been tested for their after-wear properties. Membranes are now finding their way into specialised items of CB clothing.

Because of the challenging properties required of these membranes, it may be necessary to modify available membranes using various techniques. Several methods have been used to modify the surfaces of membranes to tailor the properties of the membranes. In this case there is special interest in optimising the permselectivity of the membranes to achieve a balance of maximum moisture vapour transport with minimal transport of hazardous chemicals. One technique which has been used successfully with membranes for other applications, such as water desalination by reverse osmosis, is ion

Eugene Wilusz of the US Army Natick Soldier Research, Development, and Engineering Center discusses the next generation of chem/bio protective clothing

implantation. In this process a membrane is exposed to an ion beam. The beam penetrates the surface of the membrane and causes chemical changes at a certain depth below the surface, resulting in formation of a graphitic layer. Another method involves halogenation of the membrane surface through exposure to a plasma. A third technique involves self-assembled monolayers and bilayers of cyclic molecules which can be formed on the surface of the membrane through Langmuir-Blodgett methods. With the proper selection of pore size in the cyclic molecules, the chemicals reaching the surface of the matrix membrane can be controlled.

For many years CB protective clothing was developed and fielded on the basis of chemical testing of swatches of material along with their physical and mechanical properties. If good barrier properties were observed with the material, the material was fabricated into a garment, field tested, and adopted for use. The final garment, as a whole, was never subjected to a chemical test because such a test did not exist. The development of full systems tests evolved only after a considerable period of time and effort. A full systems aerosol test was developed first, and eventually a full systems chemical vapour test was developed. The need for a full systems test is fairly obvious if one considers that most CB ensembles are not totally encapsulating. Therefore, penetration of hazardous chemicals and biological agents through a garment can occur either directly through the material or through the interfaces in the ensemble which are not completely sealed.

The full systems vapour test was developed during the 1990s. This test has evolved to become an important test in the final acceptance of a developmental garment and is used by several countries now. The basis for this test is to expose full ensembles to a vapour challenge in a chamber for a certain period of time. Samplers are placed under the garments to collect any vapour which may penetrate the garment. The samplers are then analysed and the protection levels of the suits assessed. The most realistic way to do the test is to use human subjects. In this case, a non-toxic chemical is used as the challenge. The non-toxic chemical is chosen to simulate some of the characteristics of a hazardous chemical. This test is sometimes called the Man-in-Simulant Test (MIST). Methyl salicylate is commonly used as a chemical warfare agent (CWA) simulant. The typical test is a two-hour exposure with human subjects engaged in work-rest cycles. A variety of activities stress the ensembles using motions which might be encountered in the field. Physiological characteristics, such as body core temperature, can also be monitored. Mannequins can be used for these tests in lieu of human subjects. Mannequins can either be static or articulated with a variety of motions. A number of different mannequins are in use in different countries. Live CWAs can be used in conjunction with mannequins if the appropriate facilities are available.

All dressed up and no strength to go. It will take a revolution in IPE to break the protection/physiological burden link ©DoD

Full systems vapour testing has now

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been accomplished for more than a decade, and considerable results have been generated. It has become clear that the results observed are highly dependent on the closure systems used at the interfaces in the garment. A bellows effect occurs with impermeable materials as a result of the pumping action caused by the motions the suit is experiencing. In the absence of proper closure systems, this bellows effect can cause a significant amount of vapour or aerosol to be transported into the garment. Closure systems have been designed to address this matter with membrane-based suits, and excellent protection has been observed with these new designs. In some cases a one-piece coverall is preferred to a jacket and trouser design.

One possible issue associated with CB clothing is that of tearing. Military clothing experiences a great deal of abuse, and tears invariably occur. These tears can be repaired with tape in the field. Such tears may be a greater concern in membrane-based suits than in suits containing activated carbon. With the latter, there is some carbon available to scavenge whatever vapours may be penetrating. With membrane suits it will be necessary to repair any tears with tape as soon as possible. It may evolve that some membrane suits will contain small packets of activated carbon on the inside as an extra precaution to scavenge any penetrating vapours. At any rate the field repair procedure should be similar regardless of the basic type of suit.

Combat missions, temperature and other protective devices all need to be considered in the physiological loading ©DoD

A heavy burden

Advances in materials technology are leading to CB clothing that is lighter weight and more comfortable. This clothing will, of course, still have to be paired with an appropriate respirator. New developments have led to improved respirators as well. This combination of clothing and respirator invariably is accompanied by physiological burden. While this burden can be reduced, and is being reduced, it cannot be completely eliminated. Membrane-based CB clothing systems have the potential to serve as CB duty uniforms. The current concept is that of an over-garment which is doffed over standard combat clothing. It is anticipated that such garments can be employed in the future in scenarios where there is a creditable threat. Replacement of the over-garment concept with that of a CB duty uniform will dramatically decrease the burden associated with this type of protective clothing.

Finally, it is desired to introduce self-detoxification into CB clothing systems. It is expected that agent-reactive catalysts and antimicrobial treatments can be incorporated into textile systems to impart the desired properties. Such a clothing system would allow for safer operation in a contaminated environment and increased safety upon doffing and disposal of the contaminated garment. To this end, considerable progress is being made. Agent-reactive catalysts such as enzymes and metal oxide nanoparticles have demonstrated the ability to detoxify CWA simulants in the laboratory. Some of these reactions are quite slow, and improvements in reaction time are needed. Antimicrobial treatments have also shown considerable promise. Chloramines and quarternary ammonium salts are among the approaches being studied. While many challenges remain, it is anticipated that a lightweight, self-detoxifying CB duty uniform will be developed in the not-too-distant future.