BodyTeq™ Apparel, Inc.

Cooler Fabrics for Protective Apparel

By Jeffery O. Stull

For years, the apparel industry has focused on material technology for fabrics that offered greater protection while also becoming lighter, thinner, and more flexible. Several types of protective apparel are used for protection against different hazards such as high radiant heat, hazardous materials, and rigorous physical hazards. Much of the apparel used in these situations covers a large portion of the wearer's body, creating a significant thermal burden on the individual and increasing the potential for heat stress. As a result, design philosophy has concentrated on finding ways of optimizing protection while considering ways to make the wearer both more comfortable and more productive.

One of the latest developments in fabric technology eliminates the trade-off between protection and the wearer's comfort and productivity. Developed to provide the wearer with protection from heat and flames while actively cooling the body, this new fabric technology exceeds conventional fabric performance, and can be applied either as an integrated part of a garment or as a component of a protective outfit. The ramifications of this technology are extremely important, because it means that apparel can be created that provides protection and lowers thermal burden at the same time.

The Problem of Heat Stress

Any protective outer clothing will have an impact on the wearer's comfort and physiological state. If that clothing also has to be worn in a warm environment, the effects will be more pronounced, putting the wearer at risk for heat stress.

Heat stress encompasses heat-induced illnesses, injuries, and reduced productivity that occur in situations in which the total heat load (from both environmental and metabolic sources) exceeds the body's capacity to maintain normal body functions without excessive strain. Essentially, if the heat coming into the body is greater than the heat going out, the body's accumulation of heat will raise the body core temperature, which must operate within a narrow range, between 96.8 and 100.4 degrees Fahrenheit (36° to 38°C), to maintain normal (non-stressed) functioning. If the body core temperature rises above this range, body systems become affected with the onset of heat stress.

Heat stress manifests itself in many forms, among them heat rash, heat cramps, heat exhaustion, and heat stroke. Heat stroke is by far the most serious, and can be deadly if immediate action is not taken to reduce body core temperature. And as body core temperature increases, a number of symptoms can have a profound effect, such as dizziness, nausea, and confusion. Even when workers only "feel hot," declines in productivity can be expected.

It's difficult to obtain reliable statistics on the incidence of heat stress, because it may manifest itself in the form of other injuries or ailments. It is often not reported as a heat illness to the U.S. Department of Labor's Bureau of Statistics because it's difficult to separate accidents (trips, falls, or physical contact with a hazard) that occur as the result of reduced attention or discomfort brought on by heat stress. The National Institute for Occupational Safety and Health (NIOSH) notes:

"The frequency of accidents, in general, appears to be higher in hot environments than in more moderate environmental conditions. One reason is that working in a hot environment lowers the mental alertness and physical performance of an individual. Increased body temperature and physical discomfort promote irritability, anger and other emotional states which sometimes cause workers to overlook safety procedures or to divert attention from hazardous tasks." (Working in Hot Environments, NIOSH, 1992.)

Four principal factors affect the potential for heat stress: environmental conditions, the level of individual activity, the physical condition of the individual, and the type of clothing or equipment being worn. Certain hot or hot and humid conditions create a greater potential for heat stress, as does increased physical activity. In many cases, the environment and required activity level cannot be controlled, and the only way of minimizing these effects is to change work schedules by introducing frequent breaks. Workers that are not in good physical condition or are affected by health problems can also create more susceptibility. The choice of protective clothing is often one of the few factors that can be altered in avoiding heat stress.

Fabric effects on potential for heat stress

Protective clothing affects body core temperature by restricting the normal modes of body cooling. The body *gains* heat by exposure to the environment and through the metabolic generation of heat. Heat *loss* occurs through convective, conductive, and radiative heat exchange in combination with evaporation of sweat.

The body uses blood circulation for moving heat from the body's core to the skin where it can transfer to the outside environment. Convection occurs when skin temperature is higher than the air surrounding the body, and is facilitated by air movement. Conduction results when the skin is in direct contact with clothing or other material that can absorb heat. Radiative heat loss is relatively small, but is based on the temperature difference between the body and another object.

Clothing confounds these mechanisms because it traps a small air layer immediately next to the skin. With activity and warm conditions, this air layer becomes heated, reducing the effectiveness of both convective and conductive heat losses. This air layer also becomes humidified through sweating and restricts the exchange of air with the outside environment. Since sweat evaporates most readily in low-humidity environments, evaporative heat transfer is reduced. The burden on he individual wearer is further increased when the overall environment is hot and/or humid combined with high levels of physical activity.

In general, heat-resistant clothing must often cover most of the wearer's body and some applications require relatively heavy and bulky protective clothing to provide adequate insulation from heat. The fabric used in this type of clothing works to create multiple air spaces from layering materials or using "batt"-like constructions. Thereby, the same principal that is used to provide protection from thermal hazards creates a new hazard in itself, potentially overheating the wearer.

The impact on the wearer can be worsened if insulative clothing is combined with aluminized fabrics for radiant heat protection. To achieve a high degree of reflectivity, aluminized fabrics incorporate a non-breathable film that does not allow the flow of air or water vapor transfer through the material. Other applications require a barrier against hazardous substances. Barrier clothing tends to encapsulate the wearer and in some cases, as in full body suits used for protection from hazardous chemical exposure, create a total envelope around the end user.

The barrier nature of some coated or film-based fabrics that prevent chemical permeation also prevent air and sweat from carrying heat away from the wearer's body. In less hazardous exposure situations, "breathable" fabrics that incorporate microporous films may be used. These films prevent liquid or particle contact with the wearer's skin, but also limit the effectiveness of natural body cooling, especially under extreme environmental conditions or heavy workloads.

Applications involving extreme environments are not the only situations that create the potential for heat stress. Hard work in any hot environment can also lead to heat-induced illnesses. Activities such as outdoor construction or maintenance in the summer, or work in the mining, manufacturing, and utility industries, can easily create circumstances that result in heat stress. A number of specialty user applications also exist where cooling is needed. For example, race car drivers cannot afford to add extra weight to their vehicles for cooling purposes; their reliance on garments for full body protection against accidents is made more difficult by the hot conditions in the driver compartment of the car.

Existing body cooling approaches

Until recently, the methods for dealing with heat stress were limited, and were aimed at addressing the individual factors influencing its onset by:

- Changing the environment (providing shade, adding fans, changing the time for the activity);
- Changing the work load (introducing work/rest cycles, providing alternative equipment or procedures that produced less worker strain);
- Improving worker conditioning (ensuring good worker hydration, encouraging better physical fitness and wellness, allowing for acclimatization); or
- Altering the protective clothing.

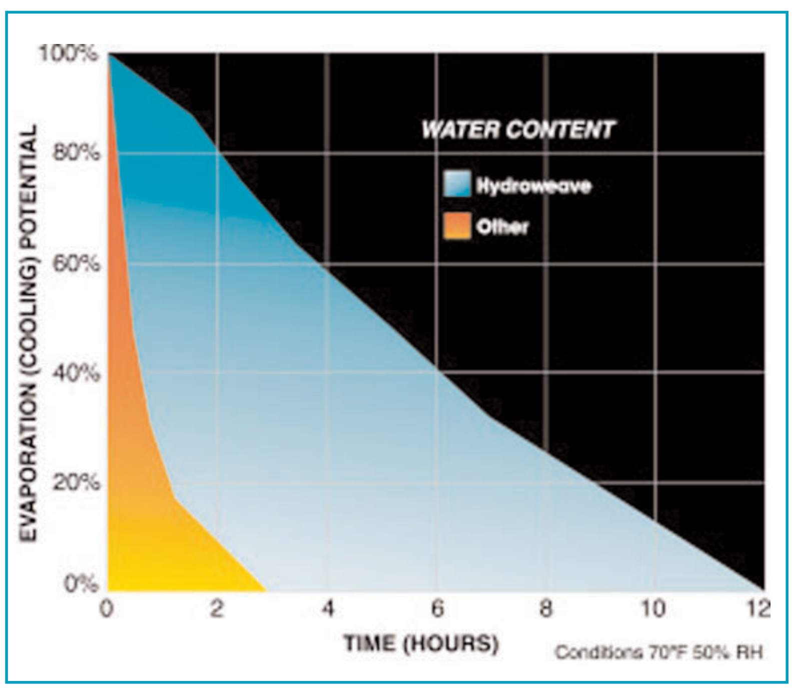
In the past, few alternatives were available for changing the properties of protective clothing. Often the circumstances of the hazards present, dictated a certain level of protection if the work was to be done. While attempts have been made to introduce protective fabrics with better "protective efficiency" and fewer tradeoffs for comfort, the types of improvements have been limited to certain applications. This meant seeking cooling from sources other than in the clothing itself.

Cooling has taken several forms, ranging from throwing wet towels over the individual to using a tethered portable air conditioner. Most portable cooling is provided in the form of a vest or similar garment which includes some form of heat transfer medium to absorb heat from the body. Typically, this medium has been non-fabric material such as water, fluid, or gel. These systems can be further classified as circulating or passive.

Circulating systems. In some configurations, water or another fluid is circulated through tubes sewn into the garment. When in intimate contact with the body, the circulating fluid picks up body heat. This type of system requires a pump, a power supply, and a heat sink, and may require the wearer to be tethered to an external device. The heat sink absorbs the heat from the circulating liquid and returns the liquid to the vest. Heat sinks have included pouches with ice or other pre-frozen or refrigerated solid materials or have been part of a breathing apparatus. In general, these systems are cumbersome and heavy and are unsuited to many applications.

Passive systems. Passive cooling systems relay on contact of the vest with the body and use special materials incorporated into the garment to absorb heat from the body. Because there is little action required by the user to operate the system, they are generally usable in a wider range of activities. The most common types of passive systems are refrigerated or ice vests, designed with pockets to hold "ice packs," sealed liquids in pouches that must be frozen before use. As with any system, there is added weight to the wearer. In addition to the environmental conditions and individual workload, the effectiveness of the system will depend on the placement of the ice packs and their degree of contact with the wearer's skin. The effectiveness may also be diminished by vascular constriction, a condition that occurs when skin temperature is lowered too far below core temperatures. When vascular constriction occurs, blood flow is inhibited. While the wearer may feel cooler, restricted blood flow to the skin may cause core temperatures to rise.

Whatever form of equipment or clothing-based cooling is provided, the question asked should be, *"do the benefits of the cooling approach outweigh its disadvantages?"* Two of the most common disadvantages of portable cooling are weight and bulk. The additional weight of portable cooling devices places more burden on the wearer, making the individual work harder and creating greater metabolic heat. If the burden is so high that the gains in cooling are offset by the heat generated through extra work, then the value of using the cooling device is obviously suspect. Increased bulk can also reduce wearer mobility and increase metabolic load. Another disadvantage can be



incurred if the system is not simple to use or is difficult to "recharge." Problems encountered in reuse of the product sometimes distract the users no matter what perceived benefits they will gain.

Cooling fabric technology

In the last couple of years, new performance-enhancing fabric technologies have been introduced that allow modified garments to provide a cooling effect instead of relying on outside cooling sources. These materials can be grouped into three general categories:

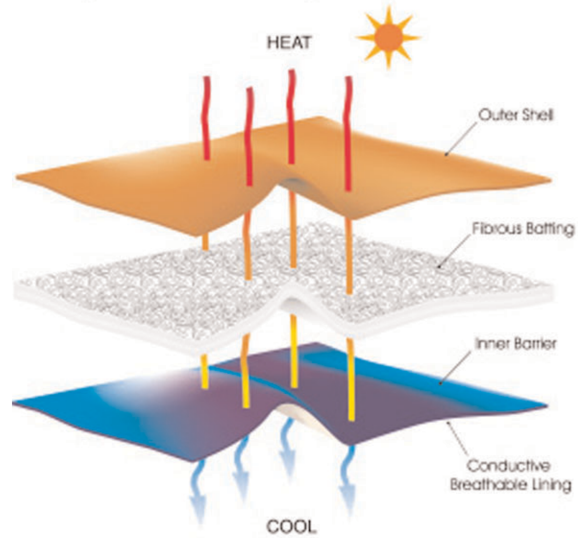
Granular materials

Phase change materials

Water-retaining fibrous-based materials.

Granular Materials are substances that readily absorb water. When incorporated into clothing fabrics, the materials are wetted before use and work on the principle of remaining wet to become a heat sink for absorbing heat from the body. (Conventional fabrics, when wetted, dry out in a few hours because they were not designed to hold moisture.) When the "activated" granules in the fabric absorb the body heat, the water in the granules evaporates, providing a cooling effect for the body. The granules are placed into channels sewn on the garment; however, the granules in these products tend to clump and separate in the fabric. Moreover, activation of granule-based cooling fabrics tends to be time-sensitive; soaking the material too long causes excess weight and bulk, and soaking it too little reduces cooling times.

Hydroweave® Composite Construction



Hydroweave's patented composite construction delivers outstanding cooling performance in a lightweight, versatile product.

The Outer Shell
Offered in a variety of woven fabrics, including cotton and fire-resistant, DuPont Nomex® brand fibers.

The Fibrous Batting
Embedded blend of super-absorbent, polymer strands within a fibrous batting. The suspended strands hold water, enhance evaporation, and promote even cooling.

The Inner Barrier
Special, microporous membrane laminated to lightweight fabric. This conductive, breathable fabric pulls heat away from the body and allows moisture to escape for keeping the user cool and dry.

Phase Change Materials. A number of companies are advancing phase change materials as a new fabric technology to enhance cooling. In this technology, a heat transfer medium is encapsulated in beads ranging in diameter from 1 micron to 5 millimeters. These beads are then impregnated in non-woven batts, foams, or on textile fibers to create an overall heat exchange fabric. As with other cooling materials, the fabric absorbs heat from the body (although many phase change materials are designed for cold-weather applications) and releases it to the outside environment. Early embodiments of this technology involved blocks of phase change materials placed in pockets of vests, in much the same way that ice pack vests are used. Nevertheless, these vests exhibited similar problems of excessive bulk, weight, and limited air exchange. New embodiments of phase change materials are aimed at regeneration by exposing the materials to the liquid/solid phase change temperature of the material (normally 60 to 75 degrees Fahrenheit).

Water-Retaining Fibrous-Based Materials. A relatively new technology in cooling fabrics is the introduction of water-retaining fibers into fabrics. This technology is similar to that used in granular materials, but instead, the water-retaining material is extruded as a fiber and blended into the non-woven batt of the material. The technology still relies on the evaporative heat transfer approach used with granular materials, but overcomes its limitations by providing a distributed water-retaining material throughout the fabric. When the non-woven batt is sandwiched between a breathable exterior fabric shell and a conductive microporous film on the fabric interior, the resulting fabric composite provides for uniform heat transfer capability after being soaked in tap water for five minutes.

One such material is Hydroweave. Hydroweave optimizes the composite fabric's performance through the judicious choice of a water-retaining polymer with a finite water absorption capacity. The selected polymer eliminates the problem of over-soaking and keeps water weight and bulk to a minimum.

Initial tests of vests made of Hydroweave show significant differences for cooling effectiveness when compared to the same activity without vests. In an evaluation conducted by Auburn University, the new technology extended work times by an average of 16.4% by lowering the rate of body core temperature increase. (These trials were based on the amount of time that test subjects dressed in semi-permeable clothing could work until their body core temperature rose two degrees Celsius.) The length and magnitude of this cooling effect will depend on several factors, including the activity level of the wearer, the temperature and relative humidity of the working environment, and the type and configuration of other clothing being worn. As might be expected, higher activity levels will reduce the effective cooling time, as will relatively high temperatures and increased humidity. In addition, the greater the surface area of the body in contact with the Hydroweave fabric, the more cooling effect that can be provided.

Other protection properties

Another aspect of the water-retaining fiber-based cooling material is its relative performance for thermal insulation in hot environments. When vests are constructed of materials and components that provide flame resistance (based on an aggressive vertical flame resistance test) and heat resistance (using the exposure of 500 degrees Fahrenheit for five minutes to determine if the material melts, drips, or separates), their potential is extended to high heat applications.

For example, in one configuration of the Hydroweave composite, the interior batt is composed of aramid fibers, the shell is an aramid fabric, and the innermost layer is flame-resistant (FR) polyurethane or a similar breathable film product. When this material is subjected to insulative tests such as thermal protective performance or radiant heat tests, the "wet-activated" fabric provides up to three times the insulation time provided by similar thickness/weight materials. In full manikin testing (under simulated flash fire conditions) with the same fabric used in a coverall design, no burns were indicated for 10-second exposures at 1800 degrees F (the equivalent exposure experienced during a severe flash fire for firefighters).

These results mean that this technology is not only capable of providing cooling but can also offer simultaneous thermal protection. Garments using this technology can be designed to have integrated cooling and protection without the need for auxiliary garments or equipment.

Industry Direction

Continued new fabric developments will seek increasingly efficient means of providing protection with the least possible effects on the end user. These development efforts will focus on the comfort and stress-reduction properties of fabrics used in apparel, or new designs of apparel that permit some relief from hot environments. Recent innovations in cooling fabrics and their continued improvement have created new possibilities for applications in which workers can be affected by the potential for heat stress. The evaluation of cooling fabrics, particularly those which offer both protective and cooling qualities, will establish a number of specific activities in which the dual benefits of reduced exposure and reduced threat of heat stress are concurrently achieved. Potential applications include foundry operations, wildland fire-fighting and welding, just as a beginning.

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