THE ROLE OF THE MOISTURE/VAPOUR BARRIER IN THE RETENTION OF METABOLIC HEAT DURING FIRE FIGHTING

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INTRODUCTION

Fire fighting is unquestionably a hazardous occupation for which highly specialized protective clothing is required. A recent development in firefighter turnout gear is "bunker clothing" consisting of high cut trousers and an overcoat. Compared with the standard "pitch coat" and rubber hip boots, the bunker clothing provides higher levels of hazard protection for the firefighter, but it also impedes the dissipation of metabolic heat

Much of this impediment comes directly from the insulative nature of the clothing in its capacity to reduce conductive, convective, and radiative heat transfer. A portion of it may, however, arise from the moisture/vapour barrier included in the new clothing. This component is intended to shield the firefighter from steam and hazardous chemical vapours, and to help keep him dry (a vapour barrier is also a liquid barrier). It interferes, however, with metabolic heat dissipation by reducing evaporation of sweat from the body. With conduction, convection, and radiation often being avenues of heat gain for the body during fire fighting, evaporation remains the only natural mechanism for passively cooling the body.

A recent development in barrier materials was the introduction of "breathable" fabric coatings, such as expanded polytetraflouroethylene (PTFE) with the trade name "Gore-tex®". These coatings are claimed to be permeable to water vapour while still providing a barrier to liquid water. Such properties would seem to identify-coated fabrics as the ideal materials for moisture barriers in turnout clothing, since they should minimize heat strain while still providing hazard protection.

This paper reports some of the findings of a large study that examined the role of the moisture/vapour barrier in the retention of metabolic heat in firefighters. Vapour impermeable barriers, vapour permeable barriers, and partial coverage barriers of both types were included. A portion of the study involved extensive laboratory trials in which firefighters performed simulated fire fighting tasks under carefully controlled environmental and physical work conditions. These laboratory trials were followed by a field trial in which actual fire fighting tasks including exposure to Dames were carried out.

METHODS

The turnout clothing consisted of 3 different outer shells (WOOL, COTTON, and NOMEX), 5 barriers (FULL-NEOPRENE, FULL-GORETEX, PARTIAL-NEOPRENE, PARTIAL-GORETEX, and NONE), and 2 thermal liners (WOOL and NOMEX) tested in a 3 X 5 X 2 factorial design in the laboratory. These bunker suits were specially designed for the study so that all elements were interchangeable. Apart from the colour of the outer shell, subjects were not aware of the barrier/liner combination being worn. In addition, subjects wore long sleeved cotton turtle-neck undershirts, cotton long-johns, wool socks, Nomex" coveralls, leather gloves, rubber boots, a helmet, and a breathing apparatus with a face mask and air tank.

Two environmental chamber conditions were evaluated. Condition HOT involved 8 subjects working for 30 min at a dry bulb temperature (T_{db}) of 30°C, relative humidity (RH) 50%, while condition VERY HOT involved 3 subjects working for 70 min (two 30-min sessions with a 10-min rest period in the chamber) at T_{db} = 35°C, RH = 45%. The field trial was conducted with 6 subjects over a 5-day period during which ambient conditions were remarkably consistent, with sunshine every day and afternoon highs of T_{db} in the range 25 - 30°C.

The simulated fie fighting tasks used in the laboratory phase of the study consisted of 3 work stations: treadmill walking at 4.5 km/h; bench stepping on 2 standard 8-in steps at 60 steps/min; and carrying 20 kg boxes a distance of 2 m across the room ai a rate of 6 transports/min (four boxes were unstacked, transported, and restacked one at a time during this task, thereby forcing the subjects to bend as well as lift and carry). Each activity was conducted for 9.5 min, with 0.5 min between activities for station rotation and a total work cycle time of 30 min. Fire fighting tasks during the field trial consisted of the following activities: walking, 5 min; hose work, 5 min; ladder climbing and chopping, 8 min; rest, 12 min; casualty search and rescue, 10 min; and fire tending, 10 min. Total activity time was 50 min, with the air tank replaced during the rest period

The physiological parameters recorded and analyzed during the study were final mean skin temperature (FMST), delta mean skin temperame (DMST), final rectal temperature (FTRE), delta rectal temperature (DTRE), heart rate (HR), fluid loss (FLOSS), percent dehydration (%DEHY), fluid evaporated (FEVAP), air consumption (AIRCONSUM), and subjective thermal comfort (COMFORT). In the laboratory, data were recorded with a computerized data acquisition system while during the field trial portable solid state data loggers (Vitalog PMS-8) were used. The HOT laboratory data were analysed via analysis of variance (AOV) far repeated measures, but the other results could only be analysed by inspection and comparison with condition HOT due to reduced subject numbers.

RESULTS

AOV showed 2 statistically significant main effect of BARRIER for 8 of the 10 parameters examined. By comparison, main effects SHELL and LINER had only 1 instance of statistical significance each. A marginally significant interaction was noted between SHELL and BARRIER for parameter DMST, suggesting that the rise in skin temperature may depend slightly upon the specific combination shell and barrier used BARRIER had an extremely significant effect ($p < 0.0000$) on parameters FMST, DMST, and FEVAP, indicating that the composition or extent of the barrier used in the clothing profoundly affects moisture evaporation from the clothed body (fluid evaporation was 25% greater with FULL-GORETEX than with FULL-NEOPRENE, and 55% greater with NONE). Post-hoc LSD tests showed that the FULL-NEOPRENE barrier clearly imposed the greatest thermal stress on the body while the FULL-GORETEX barrier was often grouped with the partial barriers or no-barrier configuration.

The absolute levels of thermal physiological strain achieved during condition HOT were nor overly severe, although most subjects appeared very exhausted after the exposure. The highest mean FTRE recorded was 37.8°C, HR was generally between 140 - 150 bpm, and FLOSS was 0.5 - 0.6 kg over 30 min. This could have been due to the relatively short duration of the exposure. Indeed, during condition VERY HOT which lasted just over twice as long, much higher levels of strain were observed (FTRE exceeded 38.5°C; HR was between 160 - 170 bpm; FLOSS exceeded 1.7 kg over 70 min), and virtually all significant differences seen during condition HOT were amplified. Of particular note is the fact that whereas all subjects completed all exposures during condition HOT, several subjects were unable to complete 70 min of work during condition VERY HOT, and barrier FULL-NEOPRENE resulted in the shortest exposure times. The field trial results were extremely comparable and supported all of the results obtained in the laboratory.

CONCLUSIONS

This study demonstrated under a broad range of both simulated and realistic fire fighting conditions that a full vapour barrier of a material such as neoprene leads to significantly higher levels of thermal physiological strain than a vapour permeable barrier of a material like Gore-tex®. The vapour permeable barrier appears to provide its beneficial action by permitting evaporation of sweat from the body, hence increased metabolic heat dissipation, as manifested in higher sweat evaporation rates, lower skin and deep body temperature, and lower heart rates. Not to be forgotten is the subjective data that showed neoprene to be the least desirable barrier material from a thermal comfort perspective.

The design criteria for firefighter turnout clothing to provide a high degree of hazard protection concomitantly with a high metabolic heat dissipation capability are essentially in conflict. Clearly, the optimum design of turnout clothing must be a compromise between these disparate requirements. The advent of vapour permeable moisture barriers is a significant step forward in achieving this objective.