THE INFLUENCE OF FOG ON HEAT LOSS THROUGH CLOTHING

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INTRODUCTION

Fog is often perceived to increase heat loss in already cold environments. However, the physical process responsible for this increase in heat loss is not completely clear (1). In a cold environment, fog particles penetrating clothing or impinging on bare skin will evaporate upon reaching (or nearing) the higher temperature surfaces. Since evaporation is endothermic, the phase change from liquid to vapour removes a calculatable amount of heat from the surface. Thus, the heat of vaporization of the mass of water reaching the higher temperature surface should be equal to the increase in heat loss due to fog, if any increase is actually observed.

METHOD

Variable density fog was generated by an apparatus that mixed cold, dry air with warm, moist air. This fog was introduced into an environmental chamber which housed a sweating hot plate. Meteorological characteristics of the fog were determined from the visibility across the chamber with a He-Ne laser and a photocell. Visibility is related to the ratio of detected light intensities before/after introduction of fog (2) and light intensity is proportional to the square of the photocell output voltages (3),

$$V = \frac{3.91 \cdot d}{\ln(I_1/I_0)} = \frac{3.91 \cdot d}{2 \cdot \ln(v_1/v_0)}$$

where V is the visibility in meters, d is the distance between the light source and photocell, I_0, I, and v_0 and v_1 are the light intensities and photocell output voltages in the absence and presence of fog, respectively.

Heat loss was measured with and without the presence of fog. Bare skin was emulated using the surface of the hot plate covered with filter paper. Nomex® III (6.0 $oz \cdot yd^{-2}$), Gore-tex® (1ˢᵗ generation) and a single-faced fleece were studied as these represent fabrics widely used in protective clothing. To simulate the effects of air convection, air was drawn underneath the Gore-tex®, as would occur through garment openings in the presence of wind or body motion. In a separate experiment, collection of water droplets was measured by weighing the fabrics before and after exposure to fog. In addition to the measurement of visibility, mean droplet radius and mean water content were measured for the purpose of classifying the fog produced in the laboratory.

RESULTS

The characteristics of the fog were as follows. The average droplet radius was 7.69 ± 5.59 μm, the liquid water content was 11.79 ± 5.57 $g \cdot m^{-3}$ and the visibility ranged from 2.1 to greater than 580 m (Fig 1).

Heat loss coefficients for the bare hot plate covered with filter paper, single-faced fleece, and both Nomex® and Gore-tex® with a 6 mm trapped air space, are shown in Fig 2. A linear relationship between the heat loss coefficient, $h_c = Q_t/(T_p - T_a)$, and the output voltage of the photocell, v_1, was observed, where Q_t is the total heat loss per unit area, and T_p and T_a are the plate and ambient temperatures, respectively. Bare plate tests showed a definite correlation between increases in fog density and increased heat loss. The air permeable fabrics, Nomex® and fleece, showed an increased heat loss with fog density, but to a lesser extent than the response of the bare plate. Air and liquid impermeable Gore-tex® with a 6 mm trapped air space showed no significant change in heat loss due to the presence of fog. When infiltrated with air containing fog (@ 0.4 l/s), Gore-tex® responded with a significant increase in its heat loss coefficient.

If the increase in heat loss coefficient is due to liquid water evaporating from the clothing surface, its magnitude must be proportional to the rate of collection of liquid water per unit area, dm_c/dt, by the clothing surface. Experimental conditions were such that water could evaporate as fast as it was collected. The additional heat loss from the plate is, $Q_e = \varepsilon \cdot L_v \cdot (dm_c/dt)$, where L_v is the latent heat of vaporization of water, dm_c/dt is the rate of evaporation per unit area, and ε is the evaporative efficiency. Using a theoretical evaporative efficiency based on fabric properties (4) and the measured rate of water accumulation, allows for calculation of the theoretical heat transfer coefficient before and after the introduction of fog, $h_c' = h_c + (Q_e/(T_p - T_a))$, for each fabric system. These values (Table 1) were calculated for no fog (v_1 = 1.56 V; V = 580 m) and a very dense fog (v_1 = 4.0 V; V = 2.1 m). In the case of air infiltration underneath Gore-tex®, only the change in heat loss coefficient is predicted.

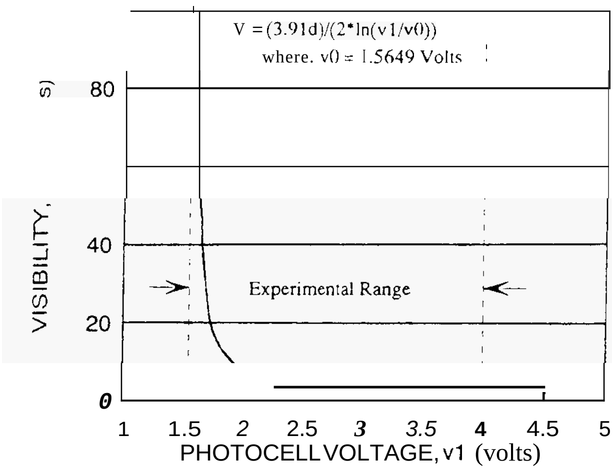

Fig. 1 - Visibility vs. photocell voltage

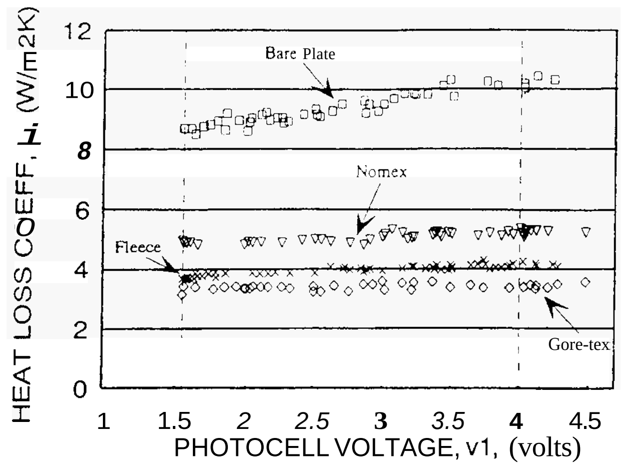

Fig. 2 - Effect of fog on fabric systems

Table 1 - Experimental and Theoretical Coefficients of Heat Loss (before/after fog)

Fabric System	h_c (no fog; v_1=1.56 V)		h_c' (fog; v_1=4.0 V)		% Change	
	Exp	Theory	Exp	Theory	Exp	Theory
Bare Plate	8.72±0.25	8.67	10.16±0.14	9.50	16.5	9.6
Nomex®	4.93±0.07	4.90	5.21±0.09	5.12	5.7	4.5
Single-faced fleece	3.75±0.07	3.81	4.15±0.06	4.10	10.8	7.7
Gore-tex®	3.12±0.06	3.11	3.35±0.07	3.34	7.3	7.6
Gore-tex (infiltrated)	20.69±0.19	N/A	21.96±0.30	N/A	6.1	4.0

CONCLUSIONS

Measurable increases in heat loss were evident in all fabric systems, although the magnitude is probably significant only for the bare plate (16%) and air infiltration conditions, and even then was small. In a very dense fog, the size of the changes in heat loss were comparable to those expected on the basis of the vaporization of water mass collected per unit time, by the fabrics. It is unlikely that the effect of fog on the heat loss through clothing makes a significant contribution to the thermal state of people exposed to cold/wet environments. However, the effect may be large enough to be perceived.

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