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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

MATERIALS SUITABLE FOR CLOTHING AIRCRAFT FIRE CRASH RESCUE WORKERS

PART VI. THE EFFECT OF WATER ON PROTECTION

by

D. L. Simms and G. C. Karas

Summary

The effect of moisture content on the protection afforded by various clothing assemblies against radiation or flames has been measured. Some of the factors involved in producing scalding when an individual is "wetted down" are discussed.

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1. Introduction

The previous investigations into protective clothing for fire crash rescue workers (1, 2, 3, 4, 5) have been carried out at normal moisture contents. This paper describes experiments to investigate the effect of variation in moisture content upon the protection afforded by the principal materials used for protective clothing.

The moisture content of clothing depends upon the local temperature and relative humidity: these depend upon the temperature and relative humidity of the atmosphere and on the rate of perspiration of the wearer. In these experiments, different levels of moisture content were obtained by first drying and then conditioning the clothing at different relative humidities at approximately one temperature. In practice the moisture contents of the different components of a clothing assembly are not the same; some values of the regain or the ratio of the weight of the conditioned material to its dry weight are given in Table I.

Table I

Relative Humidity	60%	98%
Material	Regain	
Cotton	per cent 12	per cent 174
Gaberdine 80% wool 20% cotton (waterproofed)	7·5	23
Fearnought	31	188
Wool pile	5·2	136
Open mesh fabric	4·6	215

A valuable method of affording relief to a rescue worker is to keep his clothing wet (6) while exposed to fire. Experiments were therefore made to test whether under such conditions there was a danger of scalding from the conversion of the water into steam.

2. Experimental Procedure and Results

The materials tested are listed in Table II.

Table II.

Purpose	Description	Appearance	J.F.R.O. ref. No.	Thickness mm	Weight per unit area g/cm2
Outer Materials	Aluminised Asbestos		R.165	1·3	0·10
	Aluminised cotton		R.166	1·1	0·05
	Fearnought (wool not flameproofed or water proofed.)	white	R.154	2·9	0·08
	Lasting cloth (wool not flameproofed).	white	R.178	1·9	0·06
	Asbestos cloth.	white	R.179	1·2	0·08
Inter-lining	Wool pile (cotton backed).	white	R.177	4·0	0·045
	Open mesh fabric (cotton).	white	R.148	5·1	0·05
Lining	Cotton poplin	off white	R.119	0·45	0·025

The assemblies were conditioned to equilibrium with atmospheres at four different humidities; oven dried, 38 per cent relative humidity at 24°C, 60 per cent at 22°C and 98 per cent at 25°C.

2.1. Moisture content experiments

The flame test described in detail elsewhere was used for these tests (2). As only comparative tests were required the horsemeat in the test assembly was replaced by two ½ in. thick asbestos blocks, a less variable material. The outer face of the fabric was exposed to petrol flames and the temperature of the surface of the block at the back of the assembly was measured by means of a copper disc ½ in. in diameter and 0·08 in. thick, having a 38 s.w.g. copper constantan thermocouple attached to it. The time taken for the surface of the block to rise by 25°C was noted.

The results of these tests are shown in Figure 1.

2.2. Wetting Down Tests

As in this series of tests, a stream of water was to be applied directly to the test specimen and the danger of free water falling into burning petrol had to be avoided, the radiation test (2) was used. The apparatus is illustrated in Plates I and II, water was applied from a batswing burner (rectangular opening 1 mm x 2 mm) at the rate of 750 ml/min (0·17 imp. gallons per minute). The velocity of impingement was approximately 2·5 in./sec. The water emerged from the nozzle in a triangular sheet striking the cloth along a horizontal line 3·5 cm wide at an angle of 135° to the downward vertical. The experiments were carried out in front of a panel at intensities of radiation of 2 w/cm^2 and 4 w/cm^2.

The water was turned on when the temperature of the lining had reached 25°C. This would be about as high a temperature rise as could be tolerated by fire fighters. The jet was allowed to play for five seconds and a temperature-time record taken.

The experiments were repeated with a P.V.C. sheet (0·012 cm thick) interposed between the outer garment and the interlining. This would normally not contribute significantly to the thermal protection and was used to find the effect of impermability.

It was found that usually, over and above the normal temperature time curve there was a sharp rise in temperature when the water struck the clothing. There was no extra temperature rise for Fearnought nor for any assembly with a P.V.C. sheet interlining. Typical results are shown in Fig. 3.

3. Discussion of results

Owing to the difference between the thermal properties of horsemeat and asbestos wood, the protection times given in this paper are not directly comparable with those given previously.

With horsemeat the protection times would be about one quarter greater than the values quoted.

3.1. The effect of moisture content on protection time

As the moisture content increases from zero, the protection first decreases before increasing (Fig. 1). The changes in protection may be as much as 50 per cent of its value for oven dry clothing.

The dependence of protection time upon moisture content may be interpreted in terms of the thermal properties of the materials. (Appendix). The addition of moisture increases the thermal conductivity of the materials, which tends to shorten the time for heat to penetrate to the rear surface of the assembly whilst at the same time it increases the thermal capacity, which tends to lengthen the time for heat to penetrate. The ratio of these quantities is the thermal diffusivity k. In transient conduction problems the time usually appears in the form 'kt' and $\frac{1}{k}$ is therefore a measure of the time scale. The variation in thermal diffusivity of a material with moisture content may be calculated approximately and the shape of the curve relating the reciprocal of diffusivity and moisture content is shown in Fig. 2; it is similar to Fig. 1. There may be some additional effects due to migration of moisture and evaporation of water vapour.

3.2. Wetting down experiments

With assemblies other than the one including a layer of p.v.c. the temperature rose suddenly when water was applied. Since the temperature rise, when it occurs, is very rapid it is not due to conducted heat. Its absence when a p.v.c. lining is present suggests that it is a result of the passage of steam formed in the outer layers of the clothing, and expanding both inwards and radially through the air spaces in the clothing.

The greater rise in temperature with asbestos cloth compared with lasting cloth is presumably a consequence of its greater "wettability".

4. Conclusions

When clothing containing moisture is exposed to heat the formation of steam appears to play no part in the h at transfer to the rear surface of the assembly, the effect of thermal capacity of water being predominant. There is, however, a danger of scalding if water comes

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suddenly in contact with outer clothing at temperatures above 100°C as steam may be formed which can produce sudden increases of temperature at the rear surface of the clothing. The hazard increases with the wettability of the fabric though a closely woven fabric would be less dangerous than a similar open weave one. An impermeable membrane would eliminate the danger though it might not be practical for physiological reasons.

If water is to be used to protect a fireman it should be used to wet down before he enters the fire. To wet down after his clothing is hot, could be dangerous.

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Appendix

Variation of thermal diffusivity with moisture content.

The thermal diffusivity k is defined as $K/\rho c$.

where K is the thermal conductivity,

ρ is the density,

and c is the specific heat of the material.

The thermal diffusivity of a mixture may be calculated by the methods of mixture, assuming no chemical change occurs during mixing. The swelling of textile fibres when moisture is added is neglected. It is probable that the specific heat of textile changes in a similar way to the specific heat of wood (7) but the effect has been neglected as secondary.

If n is the regain and the suffixes 1, 2 and 3 refer to the textile, and water and the final mixture respectively then the relations for three properties may be written

$$K_3 = (1 - n) K_1 + n K_2$$

$$\rho_3 = (1 - n) \rho_1 + n$$

$$c_3 = (1 - n) c_1 + n$$

The specific heat and density of water are unity.

$$\therefore K_3 = \frac{K_3}{\rho_3 c_3} = \frac{(1 - n) K_1 + n K_2}{\left[(1 - n) \rho_1 + n\right]\left[(1 - n) c_1 + n\right]}$$

The variation of thermal diffusivity for one material is shown in Figure 2.

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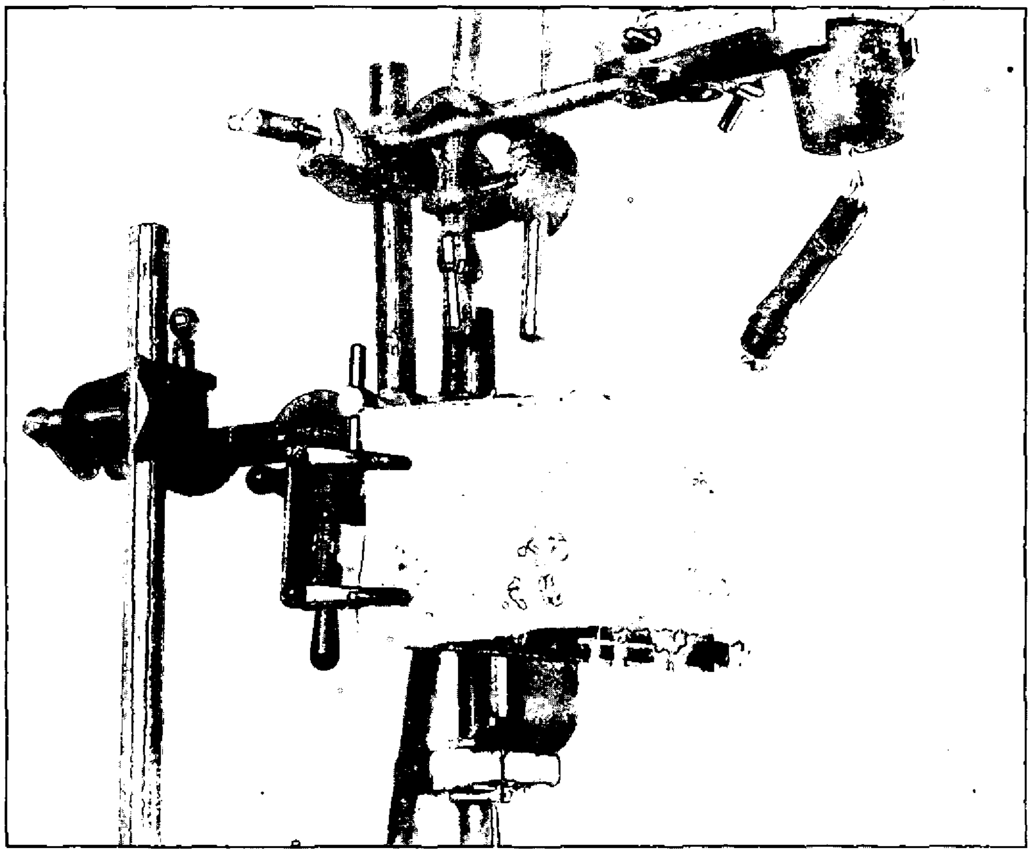

PLATE. I. THE APPLICATION OF WATER SPRAY TO ASBESTOS CLOTH

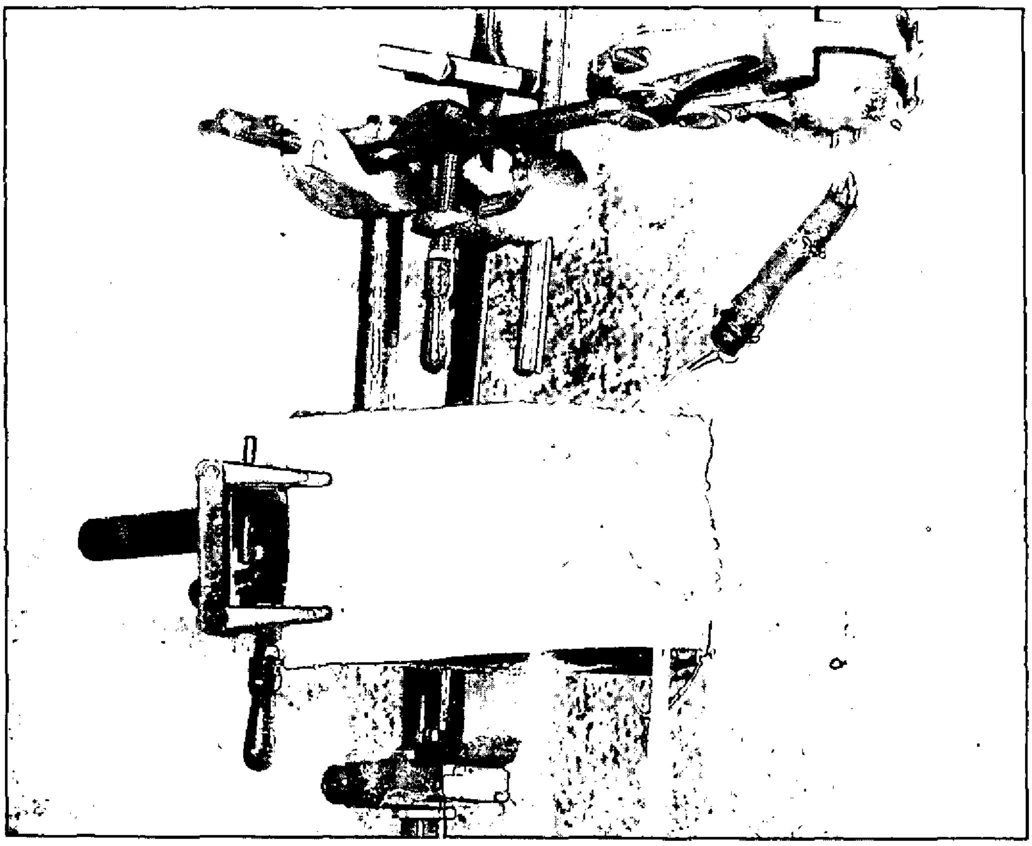

PLATE. 2. THE APPLICATION OF WATER SPRAY TO LASTING CLOTH

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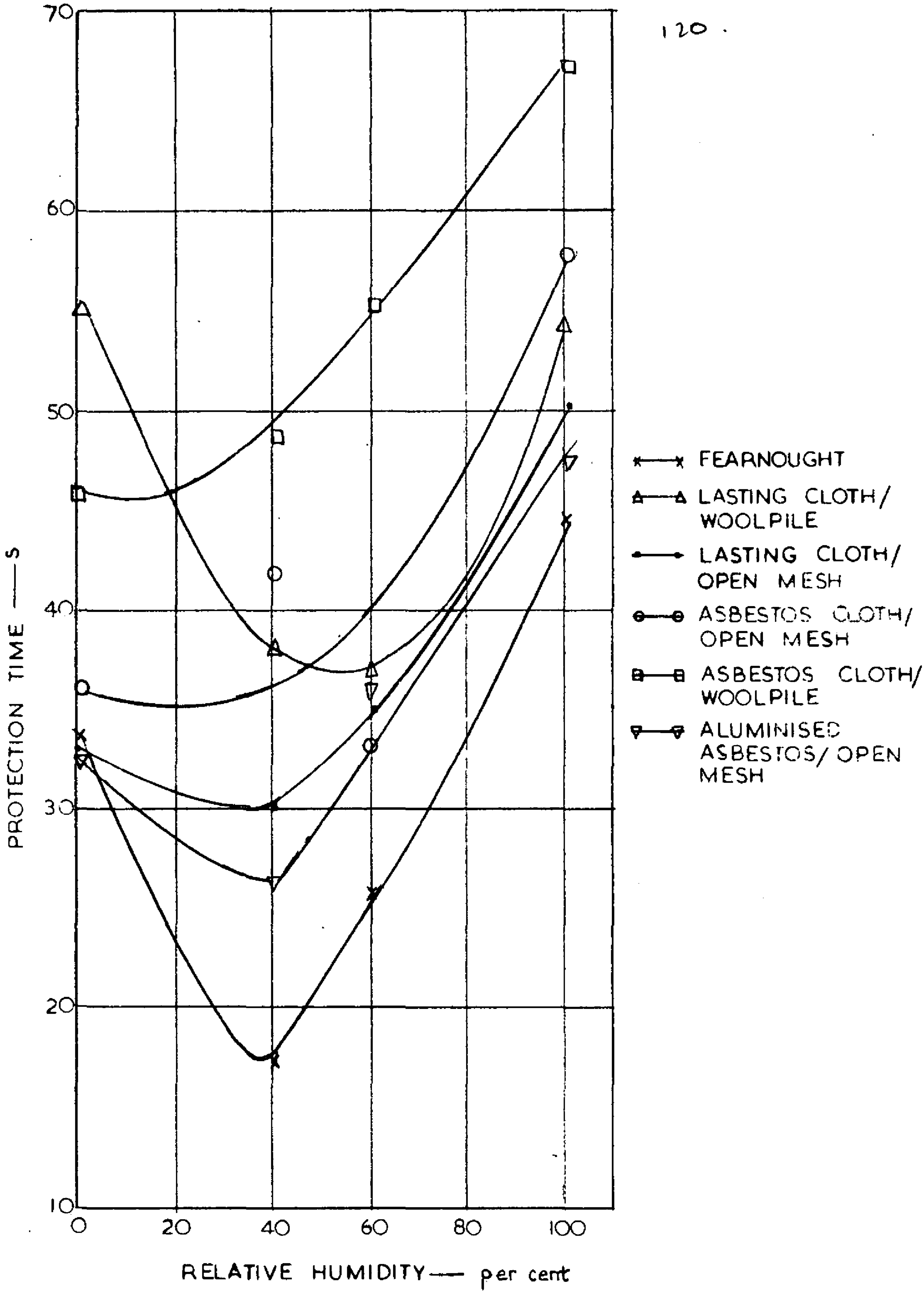
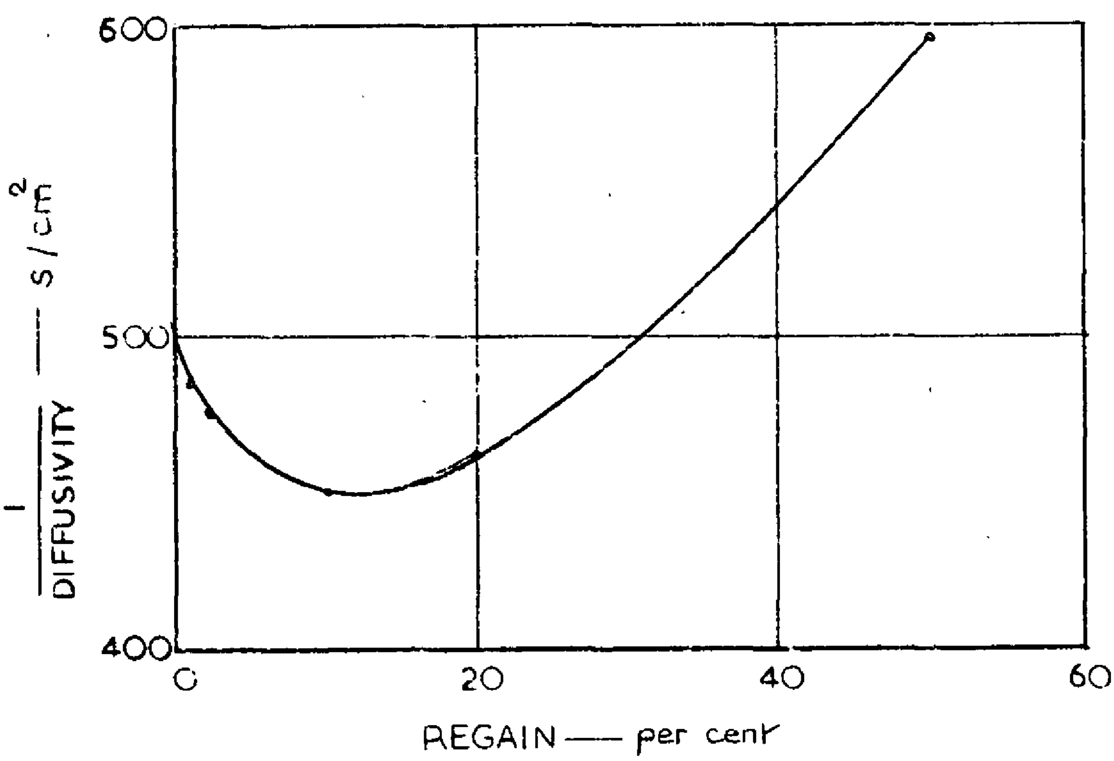


FIG. I. VARIATION IN PROTECTION TIME WITH RELATIVE HUMIDITY (FLAME TEST)



$K = 1{\cdot}2 \times 10^{-4}$ cal cm^{-2} °C^{-1} s^{-1} cm

$\rho = 0{\cdot}3$ g/cm^3

$S = 0{\cdot}2$ cal g^{-1} °C^{-1}

FIG. 2. VARIATION OF THE THERMAL DIFFUSIVITY WITH REGAIN FOR A TYPICAL MATERIAL

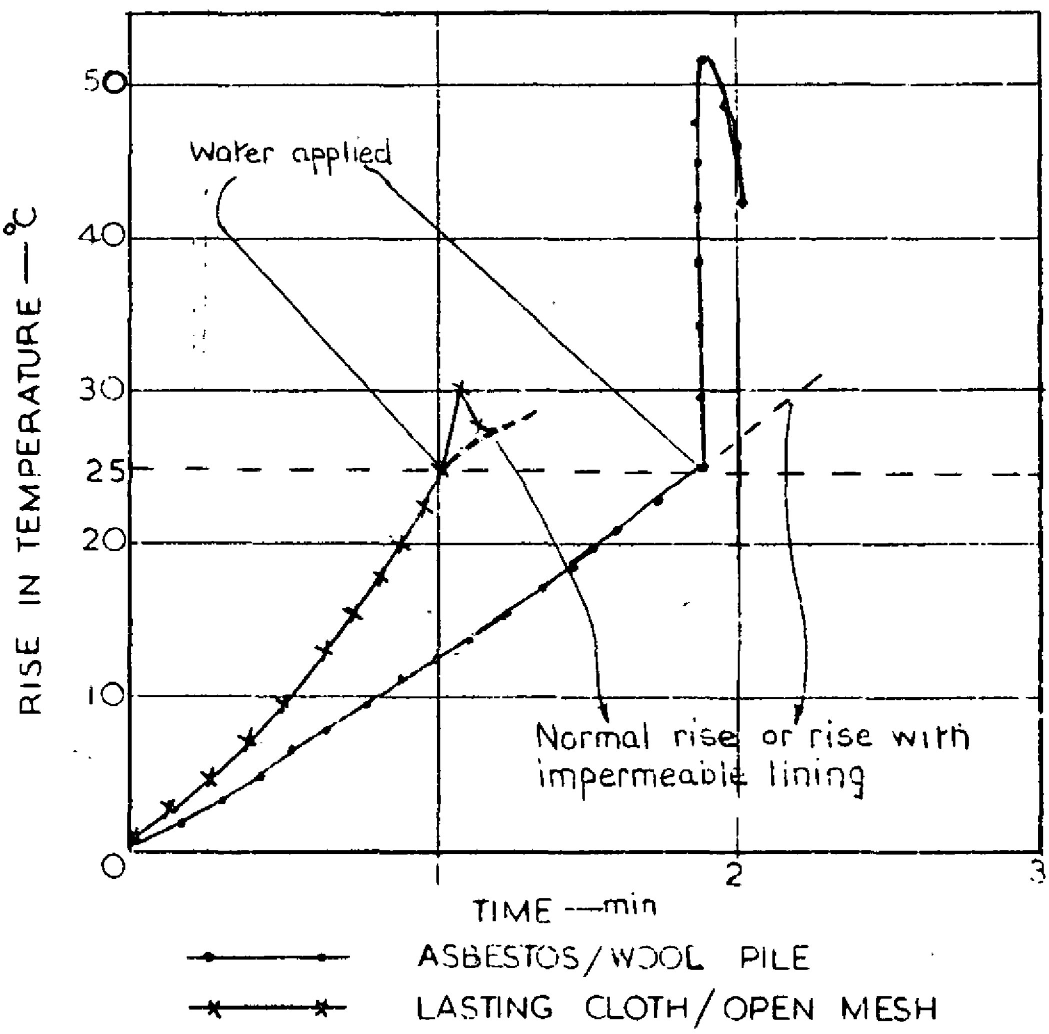


FIG. 3. TEMPERATURE RISE OBTAINED WHEN WATER IS SPRAYED ONTO DRY CLOTHING