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

THE EFFECT OF MOISTURE ON THE IGNITION AND FLAME PROPAGATION OF THIN CELLULOSIC MATERIALS

by

R. W. Pickard and H. Wraight

Summary

The effect of moisture content on the ignition of cellulosic papers of varying thickness has been studied and the rates of vertical flame speed measured. Flame spreads for all moisture contents up to 120 per cent of the dry weight. At this limiting value the rate of spread is 1/4 of the spread on dry paper.

January, 1961

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1. Introduction

The work described in this note forms part of a programme in which the factors affecting the spread of fire in forest and heathland are being studied. Most forest fires propagate through the undergrowth where the fuel consists mainly of cellulosic material with a high specific surface and a moisture content which varies widely according to the climatic conditions. The conditions under which this type of material will ignite and propagate flame are therefore of fundamental importance in any study of fire spread.

It is well known(1)(2) that the presence of moisture will affect the ignition of materials, but the range of moisture content over which these earlier investigations were carried out was small and not therefore representative of those which could occur in materials fully exposed to climatic conditions.

In the investigation described in this note the material used was sheet cellulose containing about 2 per cent carbon black to give it a uniformly high absorptivity to radiation. The thickness of the sheets ranged from 0.05 mm. to 0.78 mm. and moisture contents up to about 150 per cent of dry weight were obtained. In addition to the effect of moisture on the spontaneous ignition of this material, its effect on the vertical flame speed was also examined.

2. Experimental procedure and results

The following procedure was adopted for the ignition tests. The cellulose was cut into specimens 2 in. square and conditioned to moisture contents up to 150 per cent. Moisture contents below 30 per cent were obtained by storing the specimens over water in a sealed vessel, and above this by immersing the specimens in water and then allowing them to dry out partially. In each case the moisture content was determined as a percentage of the dry weight.

Each specimen was exposed to thermal radiation from a gas-fired furnace panel at an intensity of 1.2 cal/cm^2/s. This level of radiation was chosen since it was found that the ignition time was long enough, even with the thinnest specimens, for any effect of moisture to become apparent. At intensities below 1.2 cal/cm^2/s the thinner specimens charred away before ignition occurred. The time taken for spontaneous ignition to occur was noted. At each moisture level six specimens were tested and a further three used for determining the moisture content. The thickness and density of the sheets used in these experiments are given in Table 1.

Table I

Thickness and density of cellulose sheets

Sheet No.	Thickness mm.	Density gm/cm^3
4097	0.05	0.71
4091	0.17	0.64
4096	0.78	0.65

The mean times to ignite for the three thicknesses of sheet are plotted against the moisture content in Fig. 1.

A few experiments were made to examine the effect of moisture on the vertical flame speed*. Specimens 12.5 in. x 1 in. were suspended vertically and the lower edge ignited. The time taken for the base of the flame to travel 12 in. was noted. It was found that with moisture contents above about 120 per cent the flame went out after a distance of 2 - 3 in. Fig. 2 shows the variation in mean vertical flame speed with moisture content for two thicknesses of cellulose over the moisture content range for which the flames spread 12 in.

3. Discussion of results

(a) Ignition

Fig. 1 shows the increase in the time required for spontaneous ignition for various levels of moisture content. If it can be assumed that the whole specimen is dry before ignition occurs and that the time required for the drying is short compared with the total time for ignition t, then the effect of moisture on the physical properties of the material may be neglected, as well as the heat losses during the evaporation of the water. The time required to ignite the specimen can then be regarded as the time which would be required to ignite the specimen were it dry, t_o, together with the time required to evaporate the moisture, t_w.

$$\text{Thus } t = t_o + t_w \qquad (1)$$

Assuming an absorptivity of unity and neglecting heat losses during the evaporation of the water

$$t_w = \frac{\Delta \rho_o m L}{I} \qquad (2)$$

where Δ is the thickness of the specimen

ρ_o is the dry density of the specimen

m is the moisture content

L is the latent heat of steam

and I is the intensity of radiation

$$\text{Hence} \qquad t = t_o + \frac{\Delta \rho_o m L}{I} \qquad (3)$$

This simple theory predicts a linear relation between t and m, the slope of the lines being $\frac{\Delta \rho_o L}{I}$. Table 2 compares the measured slope with that calculated from the above expression.

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*To obtain a steady speed longer strips are required, but owing to the small amount of thin material available, these short strips were used. The results are thus comparative.

Table 2

Measured and calculated slopes

Thickness of specimen cm.	Measured slope	Calculated slope
0.005	1.4	1.5
0.017	5.2	5.1
0.078	32.8	23.5

It can be seen that while there is good agreement between the measured and calculated results for the thinner specimens the theory predicts a slope which is about 40 per cent lower than the measured value for the thickest specimen.

One reason for this discrepancy may be that the heat losses during the evaporation of the water have been neglected. With the thin specimens it is probable that they maintain a nearly uniform temperature of 100°C. during the evaporation and the heat losses will be small. With the thickest specimen, however, the temperature difference between the exposed and rear face will be larger(3) and water vapour may be forced to the rear face where it will condense. Thus the front face of the specimen may be at a temperature much higher than 100°C before it has dried out, with a consequent increase in the heat losses.

If the mean temperature rise during evaporation is Θ and H is the Newtonian cooling constant, then the time taken to evaporate the water is given by

$$t_w = \frac{\Delta \rho_0 \, m L}{(I - 2H\Theta)} \qquad (4)$$

Using this expression in Equation (1) shows that the effect of taking heat losses into account will be to increase the slope of the line of t against m. The value of Θ will increase with the thickness of the specimen and the results suggest that for the thinner specimens $H\Theta$ may be neglected in comparison with I, but not for the thickest specimen.

(b) Flammability

Fig. 2 shows the reduction in vertical flame speed with increasing moisture content. Although no measurements on flame size were made the flames were observed to be smaller, the wetter the material. At moisture contents above about 120 per cent of the dry weight, flame did not propagate vertically, though there was a finite flame speed at this value. It is interesting to note that over this range of moisture content (0 - 120 per cent) the flame speed is reduced by a factor no more than 4 and the threshold for vertical flame propagation is as high as 120 per cent moisture.

Common experience suggests, however, that a material in bulk such as occurs in forest undergrowth with as much as 120 per cent moisture content will either not be ignited from a small source, or if it is, the rate of growth of fire will not be as high as 1/4 that of a dry pile.

The reason is that in the growth of fire in bulk material, flame has to spread horizontally from one fuel element to another whereas these measurements were of vertical spread over a homogenous medium. Increased moisture content reduces the flame size on the burning element and hence the total radiation emitted, and thus decreases the possibility of ignition of the exposed fuel element. Thus the critical level of moisture content above which fire spread is possible is likely to be very much less than the value found in these experiments, and below the critical moisture content, the rate of growth may vary by more than the factor of 4:1.

Conclusions

The increase in the time required for the spontaneous ignition of thin cellulosic materials with high moisture content may be adequately accounted for by the additional heat required to evaporate the water from the material. While a simple theory neglecting heat loss may underestimate the ignition time for materials above about 0.2 mm. in thickness, it is probably adequate for applying to the majority of undergrowth materials responsible for fire spread, as the complexity of these fuel systems is too great to warrant a more precise theory.

Vertical flame propagation is possible on thin materials up to moisture contents of about 120 per cent.

From common experience of spread of fire in moist materials, it would seem, however, that vertical spread on a single fuel element, is not the controlling factor for spread in bulk material. Further work is therefore necessary.

References

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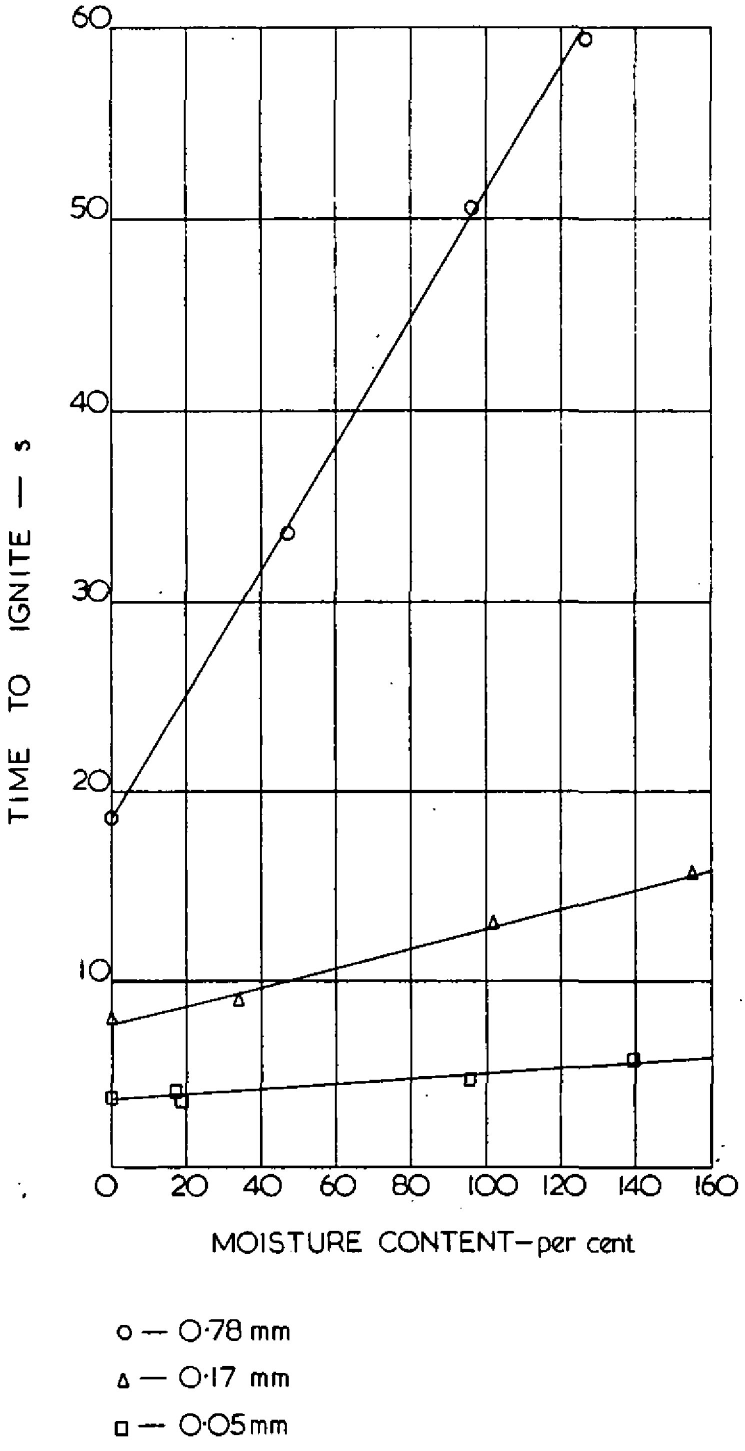

FIG. 1. VARIATION IN IGNITION TIME WITH MOISTURE CONTENT

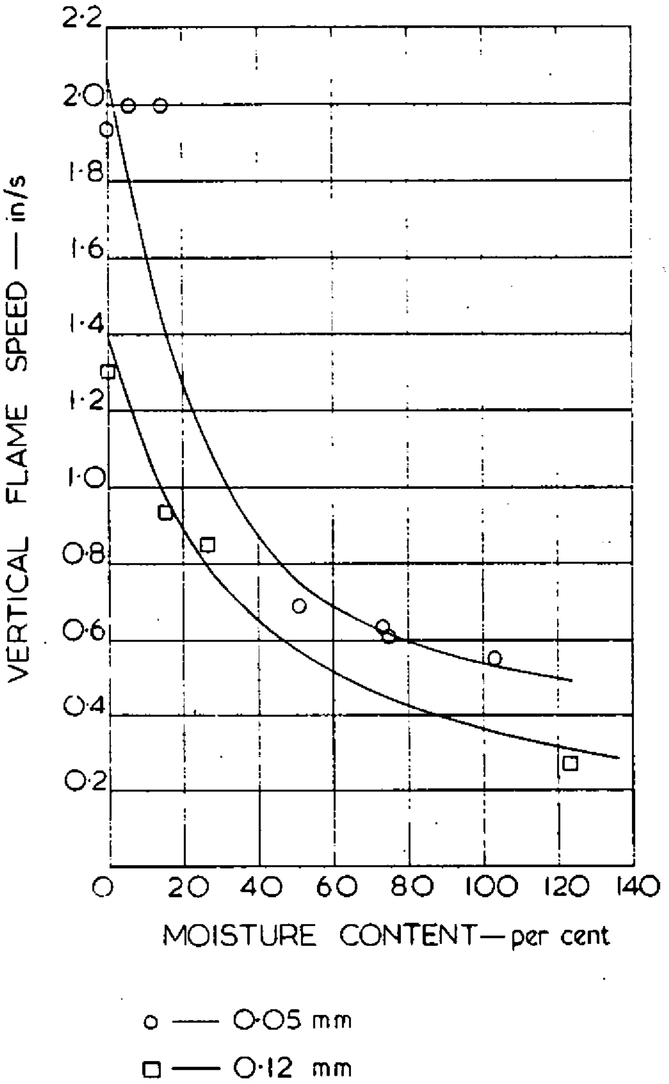

FIG. 2. VARIATION OF VERTICAL FLAME SPEED WITH MOISTURE CONTENT