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THE IGNITION OF WET AND DRY WOOD BY RADIATION

by

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SUMMARY

The effect of varying the moisture content on both the pilot and spontaneous ignition times of different woods of areas 7.6 cm square and 15 cm square has been measured over a wide range of intensities of radiation. Moisture increases the energy required for ignition; it also increases the minimum intensity for ignition though with pilot ignition its effect is only marked for moisture contents above 40 per cent.

Results have been correlated on the assumption that the material is inert and ignites at a fixed temperature. Simple heat transfer theory has been used to calculate this temperature with values for the thermal properties appropriate to the given moisture content and with allowance made within the term for thermal capacity for removing the water; the effects of moisture migration have been neglected, following the results of Williams(7).

For pilot ignition the correlating temperature is found to be 380°C, corresponding to a critical intensity of 0.31 cal $cm^{-2}s^{-1}$, except for fibre insulating board which appears to ignite at a somewhat lower temperature of 330°C. Earlier experiments, with smaller specimens, gave a similar result, of 360°C, with the results for fibre insulating board included. The present correlation extends to much longer times (up to 59 min). The results show that the choice of 0.3 cal $cm^{-2}s^{-1}$ as the maximum acceptable level of radiation for building regulation purposes, gives a larger margin of safety than was originally thought.

For spontaneous ignition the correlating temperature is found to be 545°C, the same as found previously for smaller areas, corresponding to a critical intensity of 0.74 cal $cm^{-2}s^{-1}$. The present correlation extends to much longer times (up to 16 min) and the results suggest that the empirical correction necessary for the area effects is linked with density.

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1. Introduction

It is important to know how moisture content can affect the behaviour of wood in a fire and experiments have been carried out to investigate the ignition of woods with varying moisture contents exposed to a wide range of intensities of radiation. For oven dry wood both pilot and spontaneous ignition occur when the heated surface reaches a fixed temperature(1,2) and the ignition time can be calculated using the values of the thermal properties of the dry wood, which is assumed to be inert. This note discusses the effect of moisture on the thermal properties and shows how an allowance for this effect enables the model assumed for dry wood to be applied to wet wood without further modification. It then estimates how moisture can be expected to affect the ignition of wood in practical conditions.

2. Experimental method and results

Since it is now known that the spontaneous ignition time decreases as the area irradiated increases(2) it is desirable to experiment with as large a specimen as possible but clearly the size chosen is limited by the size of the radiation source. For these experiments the source was a 30 cm square radiant panel(3), and the specimens of wood could be no larger than 7.6 cm square if they were to be uniformly irradiated for intensities as high as 1.8 cal $cm^{-2}s^{-1}$. This size gives results close to those for an infinite area(2). A few results from another series of experiments were already available for specimens 15 cm square but these had been exposed to lower intensities of radiation.

The specimens used in the pilot ignition experiments were also 7.6 cm square, and these, as for spontaneous ignition, should give results close to those for an infinite area.

The specimens of wood were oven dried and then conditioned to moisture contents of approximately 20, 40 and 60 per cent of oven-dry weight by repeatedly dipping them in water and allowing the water to sink in. This undoubtedly leaches out some volatile material but the effect on the ignition time is unlikely to be important(4). The densities of the woods were obtained from their volumes and weights when oven dried at 95°C. Variations in density between individual specimens of the same type of wood were found to be small.

The details of the specimens are given in Table 1 for the spontaneous ignition and Table 2 for the pilot ignition experiments.

The experimental procedure was similar to that described earlier(5) except that a modified water cooled Moll thermopile was used to measure radiation instead of the Thwing type radiation pyrometer. The pilot flame was put as near as possible to the top front edge of the irradiated surface, (Fig. 1.), since this position gives the shortest ignition time(2). Specimens were exposed to radiation from the panel until they ignited. If ignition occurred, the next specimen was exposed to a lower intensity of radiation until eventually it was reasonable to assume that ignition would not occur, i.e. until the rate of production of volatiles became very low. With both pilot and spontaneous ignition, flame could often be seen to appear in the volatile stream and then flash down to the wood where it persisted on the surface. With a few specimens during pilot ignition, there was intermittent flashing between the pilot flame and the surface for several seconds before flaming finally persisted, and with a few others, the flame reached the wood but was intermittent before becoming established. For these the ignition time was recorded as the first appearance of flame. Specimens of European whitewood, other than those that were oven-dry, behaved differently from the other woods; the moisture emerged from the surface in small jets of steam. Sealing the edges of the larger specimens appeared to have little effect on the ignition time. The results for pilot ignition are shown in Fig. 2. The results for spontaneous ignition are given in Table 1. The minimum intensities at which ignition took place are shown in Figs (3) and (4).

Earlier experiments on the effect of moisture content on spontaneous ignition were carried out with smaller specimens 5 cm x 5 cm in area. The procedure was the same except that the moisture content was controlled by storing the specimens over saturated solutions of various salts. The results are reported in detail elsewhere(6) and are compared with the present results in a later section of this paper.

Experiments had also been carried out on the pilot ignition of dry specimens, 5 cm x 5 cm in area and these results(1) are also discussed later.

Table 1

Details of woods used and experimental results for spontaneous ignition

Wood	Area cm^2	Thickness cm	Density oven dry -g/cm^3	Moisture content - %	Intensity of radiation -cal cm^{-2}s^{-1}	Ignition time - s
Fibre insulating board	7.6 x 7.6	1.3	0.25	oven-dry	1.00	25
					0.97	32
					0.95	-
				20	1.50	15
					1.30	21
					1.25	33
					1.22	28
					1.21	33
					1.20	-
				40	1.50	27
					1.40	30
					1.30	37
					1.27	-
				60	1.45	45
					1.45	-
Columbian Pine (<u>Pseudosuga Taxifolia</u>)	7.6 x 7.6	1.9	0.4	oven-dry	1.20	53
					1.12	70
					1.10	70
					1.10	-
				20	1.50	37
					1.20	88
					1.20	64
					1.17	-
				40	1.50	47
					1.45	68
					1.43	55
					1.41	45
					1.40	-
				60	1.60	45
					1.58	50
					1.55	-
Oak (<u>Quercus sp.</u>)	7.6 x 7.6	1.9	0.7	oven-dry	1.80	75
					1.20	93
					1.16	-
				20	1.50	62
					1.40	72
					1.30	105
					1.28	-
				40	1.60	74
					1.55	84
					1.52	80
					1.50	-
				60	1.60	96
					1.58	94
					1.57	119
					1.55	-

Table 1 continued

Wood	Area cm^2	Thickness cm	Density oven dry -g/cm^3	Moisture content - %	Intensity of radiation -cal cm^{-2}s^{-1}	Ignition time - s
European Whitewood (*Picea Abies*)	7.6 x 7.6	1.9	0.45	oven-dry	1.35	45
					1.30	48
					1.22	–
				20	1.50	52
					1.45	56
					1.42	55
					1.40	–
				40	1.60	50
					1.58	–
				60	1.70	45
					1.68	51
					1.65	61
					1.62	–
					1.60	–
	15 x 15	2.5	0.5	oven-dry	1.1	79
				10	1.1	650
				40	1.1	1000
			0.6	oven-dry	1.1	52†
Larch (*Larix Decidua*)	15 x 15	2.5	0.5	oven-dry	1.0	130
Abura (*Mitragyna spp.*)	15 x 15	2.5	0.5	oven-dry	1.0	680
					"	360
					"	840†
Makore' (*Mimusops Heckelii*)	15 x 15	2.5	0.6	oven-dry	1.0	890
					"	100
					"	120†
					"	100†
					"	90†
Baltic redwood (*Pinus sylvestris*)	15 x 15	2.5	0.7	oven-dry	0.7	40†
					"	45†
					0.9	27†
					1.1	35†

† Edges and back surface painted with flame retardant paint.

Table 2

Details of woods used in pilot ignition experiments and range of experimental results

Area = 7.6 x 7.6 cm^2

Wood	Density g/cm^3	Thickness cm	Moisture content %	Range of intensities cal $cm^{-2}s^{-1}$	Range of ignition times - s
Fibre insulating board	0.25	1.3	dry	0.25 - 0.40	610 - 84
			20	0.32 - 0.50	555 - 80
			40	0.34 - 0.35	535
			60	0.37 - 0.45	465 - 365
		1.9	dry	0.20 - 0.30	1440 - 215
			20	0.25	1010
			40	0.24 - 0.30	2540 - 760
Oak (*Quercus sp.*)	0.66	1.3	dry	0.38 - 0.50	415 - 140
			20	0.55	605
			40	0.59 - 0.65	635 - 530
			60	0.69 - 0.75	510 - 435
	0.80	1.9	dry	0.38 - 0.40	1260 - 1115
			20	0.50 - 0.55	1020 - 630
			40	0.41 - 0.45	2580 - 2020
Columbian Pine (*Pseudosuga Taxifolia*)	0.46	1.3	dry	0.46 - 0.50	430 - 160
			20	0.54 - 0.55	460 - 500
			40	0.63 - 0.70	380 - 180
			60	0.74 - 0.76	310 - 140
	0.71	1.9	dry	0.39 - 0.40	2130 - 1440
			20	0.43 - 0.45	1940 - 1770
			40	0.39 - 0.41	3540 - 2230
European Whitewood (*Picea abies*)	0.46	1.3	dry	0.45 - 0.50	240 - 180
			20	0.52 - 0.60	610 - 370
			40	0.57 - 0.60	550 - 260
			60	0.67 - 0.70	350 - 270
		1.9	dry	0.37 - 0.39	2380 - 1520
			20	0.40 - 0.52	1800 - 300
			40	0.42 - 0.50	1520 - 530

3. Discussion of results

The effect of moisture is to increase the ignition time and energy and the minimum intensity for both spontaneous and pilot ignition. For example, the intensity of radiation required for the pilot ignition of dry wood is about half that for wood with a moisture content of 60 per cent. Similarly, at the same intensity of radiation, (say 0.5 cal $cm^{-2}s^{-1}$) the pilot ignition time may be increased from $2\frac{1}{2}$ min for oven-dry oak, to 24 min for oak at a moisture content of 40 per cent. The minimum intensity required for pilot ignition in these experiments with 7.6 cm square specimens appears to be independent of the density of the wood except for fibre insulating board which as before(1) is much easier to ignite (Fig. 3). There appears to be a sharp increase in the minimum intensity between 40 and 60 per cent moisture content.

The increased size of the specimens used for the experiments on spontaneous ignition has resulted in the minimum intensity for ignition being lowered with a consequent increase in the times taken to ignite. For example dry wood 2.5 cm square ignites in about 30 s at a minimum intensity of about 1.2 cal $cm^{-2}s^{-1}$, 7.6 cm square in about 70 s at 1.1 cal $cm^{-2}s^{-1}$ and 15 cm square in about 800 s at 1.0 cal $cm^{-2}s^{-1}$.

4. Discussion of the effects of moisture

Heat transfer within the wood affects its temperature rise and hence its ignition time and the presence of moisture increases the ignition time by changing the heat transfer in at least three ways:

(1) moisture increases the values of the thermal properties i.e. the thermal conductivity and the volumetric specific heat;

(2) heat is transferred directly by molecular diffusion of the water;

(3) evaporation cools the hotter regions and condensation heats the cooler regions.

Water vapour in the atmosphere is an inerting gas, but the effect of this is negligibly small compared with its effect on the moisture content of materials.

Williams(7) measured the temperature-time profiles in oven-dried woods, and in woods of different moisture contents of up to 30 per cent at intensities of irradiation between 2.0 and 3.1 cal $cm^{-2}s^{-1}$, using a graphite panel furnace. He found, as expected, a plateau near 100°C, the duration of which increased with increasing depth; this he suggested was due to the lower rates of heat conduction and consequently smaller temperature gradients. On the assumption that the water converted the wood into an opaque solid, the dry wood being diathermanous, Williams found it possible within a wide scatter to correlate his results, for the temperature rise, prior to local exothermic heating, using the thermal properties corresponding to the appropriate moisture contents and making an allowance for the desorption of water. This suggested that the temperature histories, both near the surface and within the body of the wood, were unaffected by moisture migration. Williams thought, however, that the heat released when migrating steam from the surface condensed in the interior was nearly enough to vaporise the liquid present there, and that it was for this reason he was able to neglect its effect.

Gardon(8) also found little effect due to moisture migration and correlated his results using a similar technique to Williams. Gardon pointed out that this kind of correlation is based on calculating the extra enthalpy required to raise the temperature of the wet wood by the same amount as the dry wood, i.e. on differences, and so that the method is not a sensitive one.

Williams(7) also calculated the rate at which the zone of vaporization moved into the solid, by a method based on the work of Von Neumann*; this divided the solid into two regions separated by an isothermal plane, the 100°C plateau, the plane of vaporisation. The rate at which this plane moves at any depth x was assumed to depend only upon the net rate of heat transfer by conduction to that depth. This led to the following trial equation for the depth x of the plane at time t

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*See for example, Crank J., The mathematics of diffusion, Oxford, 1954.

$$\frac{(kt)^{\frac{1}{2}}}{K} \text{ ierfc } \frac{x}{2\,(kt)^{\frac{1}{2}}} = \text{constant} \quad (1)$$

where k is the thermal diffusivity

and $\operatorname{ierfc} \beta = \frac{2}{(\pi)^{\frac{1}{2}}} \int_{\beta}^{\infty} \int_{\beta}^{\infty} e^{-z^2}\, dz$

When Williams analysed his data on the times at which the 100°C plateau reached a given depth, he found that equation (1) fitted them reasonably well; this was additional evidence that the effects of moisture migration might be neglected. A further set of experiments carried out using woods containing 220 per cent moisture gave similar results except that no desorption effect had to be assumed, possibly because the wood was saturated.

Fons(9) has suggested a simple means of allowing for the effects of moisture on ignition on this basis. This enables three effects, the change in the value of the thermal constants, the heat of wetting and the latent heat to be considered within the term for specific heat, viz.

$$c_m = c_o + \frac{\Delta W + 0.01(L + \theta_0)}{\theta_F} M \quad \ldots\ldots\ldots\ldots (2)$$

where c_o is the specific heat of the dry wood(10) = 0.34 cal g^{-1} $degC^{-1}$

and c_m is the specific heat of the wet wood

M is the moisture content expressed as a percentage of the dry weight.

ΔW is the heating of wetting(11) = 16 cal/g,

L is the latent heat of steam = 540 cal/g

θ_o is the temperature rise from ambient to 100°C, at which temperature all the water is assumed to evaporate

θ_F is the surface temperature at ignition

The effect of moisture content on the thermal conductivity K, of moist wood has been measured and is given by(12)

$$K_m = 10^{-4} [\rho_o(4.78 + 10.2\,m) + 0.57] / \text{[illegible]} \quad \ldots\ldots\ldots (3)$$

where $m = \frac{M}{100}$

ρ_o is density of dry wood

and suffix m denotes value when the moisture content is M.

Its effect on density, ρ, can be estimated from the method of mixtures neglecting any change in volume.

i.e. $$\rho_m = (1 + m)\rho_o \quad \ldots\ldots\ldots (4)$$

The variations in both K and ρ due to moisture are smaller than the variation in c, so that for simplicity the values for the wet wood can be assumed to apply throughout the heating period up to the time of ignition, although strictly, once the water has been driven off the values for dry wood apply and a weighted average for the heating period should be taken.

The ignition time, t, of oven-dry wood in the form of a semi-infinite solid, assumed to be inert, opaque and totally absorbing, irradiated on one face by intensity, I, and losing heat from that face by Newtonian cooling may be obtained from(2)

$$\frac{It}{\rho c\,(kt)^{\frac{1}{2}}\,\theta_F} = \beta/\left(1 - \exp\beta^2\,\mathrm{erfc}\,\beta\right) \qquad \text{..........} \; (5)$$

$$\text{where } \beta = \frac{H}{K}\,(kt)^{\frac{1}{2}}$$

$$= \frac{Ht}{\rho c\,(kt)^{\frac{1}{2}}}, \text{ the cooling modulus}$$

$$\mathrm{erfc}\,\beta = \frac{2}{(\pi)^{\frac{1}{2}}}\int_{\beta}^{\infty} e^{-z^2}\,dz$$

$$k = K/\rho c$$

and H is the Newtonian cooling coefficient corresponding to θ_F.

By substituting values of K_m, ρ_m and c_m given by equations (2), (3) and (4) and inserting the experimental values of I and t in equation (5) we shall attempt to find a value of θ_F to give a correlation.

5. Correlation of results

5.1. Pilot ignition

Previous results for dry wood, with the pilot flame in a nearly identical position, were correlated(1) using the following values, $\theta_F = 340$ degC, $H = 8 \times 10^{-4}$ cal $cm^{-2}s^{-1}$ deg C^{-1}, $c_o = 0.34$ cal g^{-1} deg C^{-1}. The correlation was satisfactory except for fibre insulating board at low values of I, i.e. at high values of $Ht/\rho c\,(kt)^{\frac{1}{2}}$ where the points lay below the line. The results for the new series of oven-dried materials are shown in Fig. 5; there is a reasonably close fit between the experimental points and equation (5) using the same constants but a better correlation is obtained by ignoring the fibre insulating board results for high $t/\rho c\,(kt)^{\frac{1}{2}}$ and using $\theta_F = 360$ deg C, $H = 8.6 \times 10^{-4}$ cal $cm^{-2}s^{-1}$ deg C^{-1}. The experimental results for the specimens of different moisture contents and densities are plotted in Fig. 6 using equation (5) and $\theta_F = 360$ deg C. There is reasonable agreement between the experimental points and equation (5) except for fibre insulating board, for which a better correlation is obtained by using $\theta_F = 310$ deg C, $H = 7.4 \times 10^{-4}$ cal $cm^{-2}s^{-1}$ deg C^{-1}. This leads to a value for the critical intensity of wood ($I_o = H\theta_F$) of 0.31 cal $cm^{-2}s^{-1}$ and for fibre insulating board of 0.23 cal $cm^{-2}s^{-1}$.

The correlation shown in Fig. 6 appears to account for both the effects of different moisture contents and of different densities on the pilot ignition time of the woods. The results for fibre insulating board are a little below those for wood, as was found earlier(1), but the residual effect associated with density for the remaining woods found earlier(1) with smaller specimens is absent here. Additionally, although the ignition times are much longer than those studied previously - nearly an hour in one experiment and several specimens took about 40 minutes to ignite - there is no sign of a trend away from the correlation even at the highest values of $Ht/\rho c(kt)^{\frac{1}{2}}$. This suggests that any effect due to self-heating (an earlier explanation(1)) is small even for fibre insulating board.

The temperature found to correlate this and the earlier results is similar and this confirms that any effect of area on pilot ignition time is small, but since the residual effect associated with density has been removed, it also suggests that the effect of area on pilot ignition time as well as on the minimum intensity for pilot ignition may be associated with the density of the wood. The rise in the value of the correlating temperature from 340 deg C to 360 deg C is due to the exclusion of the results for fibre insulating board.

Assuming that the ambient temperature is 20°C, the surface temperature at ignition is 380°C for the species of wood tested and 330°C for the fibre insulating board.

5.2. Spontaneous ignition

Previous results(2) for dry wood were correlated using the following values, $\theta_F = 525$ deg C, $H = 1.4 \times 10^{-3}$ cal $cm^{-2}s^{-1}$ deg C^{-1}, $c_o = 0.34$ cal g^{-1} deg C^{-1}. The results for the new series of oven dried woods 7.6 cm square and 15 cm square are shown in Fig. 7. There is a reasonably close fit between the experimental points and equation (5) using the same constants, except for the results for Baltic Redwood which ignited for very low intensities. Since there appeared to be no difference between the results for the other species, these have not been plotted separately. The results for the 7.6 cm square specimens of different moisture contents and densities are also plotted in Fig. 7 and there is again a reasonably close fit between the experimental results and equation (5), although the results tend to lie above the curve at long times and below it at short times.

Previous results(6) for woods cut 5 cm square with densities ranging from 0.24 to 0.66 g/cm^3 and moisture contents ranging from 0 to nearly 30 per cent and covering a range of intensities of radiation from 1.5 to 2.4 cal $cm^{-2}s^{-1}$ have been analysed in a similar way. The best fit is obtained with a value of θ_F of 525 deg C and for H of 1.4×10^{-3} cal cm^{-2} deg $C^{-1}s^{-1}$ and the results follow the trend of the curve satisfactorily (Fig 8). However, although the effect of moisture content has been absorbed by the correlation, the effect of density has not; the denser woods lie below the lighter ones, i.e. they appear to ignite at a lower temperature. This is a similar effect to that found(1) for pilot ignition of specimens of the same size, viz, 5 cm square.

No correction to the ignition times for the effect of area(2) has been applied to these results. Nonetheless, the fact that the residual effect due to density is similar to though somewhat larger than that found for pilot ignition with specimens 5 cm square and that it is not found with either form of ignition with those 7.6 cm square suggests that the area effect does depend on density. There is some evidence of a systematic effect of density in the correlations for spontaneous ignition of thick solids in the data given in reference (2); there the majority of the data had been corrected for the small area of irradiation using an average correction factor irrespective of density. Assuming that the ambient temperature is 20°C the surface temperature at ignition is 545°C for the species of wood tested.

6. APPLICATION OF RESULTS

6.1. Incidence of fires

The rate of heat transfer from burning fabrics(13) and small petrol flames(14) and from flames of similar size, such as matches, is about 0.5 cal $cm^{-2}s^{-1}$, and the time for which this heat output is maintained is usually short. For a short ignition time the intensity must be well above the minimum and thus the present experiments show that for a large proportion of the sources of ignition responsible for starting fires both indoors and outdoors, the rate of heating is only just sufficient to ignite thick cellulosic materials in the presence of a small flame. Hence, a decrease in moisture content of about 5 or 10 per cent in a wood, resulting in a similar decrease in the total amount of heat required for pilot ignition, could increase the probability of fire occurring. Further, the moisture content of fabrics exposed to the direct radiation from the sun may be lower(16) than that expected from the temperature and humidity of the surrounding air because they are likely to be hotter. The effect would probably be less marked with thicker materials because the moisture diffusion time constant is longer, but this is a possible physical explanation for the variation of the number of fires with the hours of sunshine(15).

6.2. Safe separation of buildings

In devising safe separation distances from burning buildings(17) and timber stacks(18) in order to reduce the risk of fire spreading to neighbouring property the critical intensity for pilot ignition of wood was taken as 0.3 cal $cm^{-2}s^{-1}$; ($I = H\theta_F = 0.31$ cal $cm^{-2}s^{-1}$). In none of the present results did pilot ignition occur in less than 20 minutes at an intensity of radiation less than 0.37 cal $cm^{-2}s^{-1}$. Thus, the lowest value at which the pilot ignition is likely to occur is above 0.35 cal $cm^{-2}s^{-1}$. Even at an intensity of radiation of 0.4 cal $cm^{-2}s^{-1}$, the ignition time of dry wood will be at least 5 minutes and at the lowest likely moisture content of 10 per cent, the ignition time will be 10 minutes. Such an intensity of radiation near the extreme distance at which ignition may occur will only be reached some time after the outbreak of the fire: the fire brigade should therefore have ample time to arrive and protect the exposed property. Notwithstanding this, the dry material presents the greatest danger and regulations have been based on the hazard of the dry rather than the wet material.

7. Conclusions

Increasing the moisture content increases the time for both pilot ignition and spontaneous ignition for any given intensity of radiation. The increase has been accounted for satisfactorily by using the values of the thermal properties appropriate to the different moisture contents, and allowing for the effect of heat of wetting and latent heat of evaporation within the term for specific heat, as in equation (2). This confirms Williams' calculations which showed that it was possible to neglect the effect of moisture migration on the temperature rise.

The pilot ignition time for the position of the pilot flame shown in fig 1 may be calculated using equation (5) assuming a fixed surface temperature criterion of 380°C for wood and 330°C for fibre insulating board. This correlating temperature for pilot ignition is the same for specimens 5 cm and 7.6 cm square and this suggests that the effect of area on pilot ignition time is small. The new correlation also appears to be more satisfactory than that found earlier(1) since there is no residual effect linked with density, and although fibre insulating board, the lightest material, again appears to ignite at a slightly lower temperature, there is little sign of any systematic departure from the curve at high values of $\frac{Ht}{\rho c(kt)^{\frac{1}{2}}}$ which would denote self-heating. Moisture contents of up to about 40 per cent by weight appear to have little effect on the minimum intensity at which ignition occurs, although there may be an increase above this level, but the energy required for ignition increases markedly for all moisture contents. The rate of heating from, and the energy contained in most small sources, is about the minimum required for ignition so that even small fluctuations in moisture content may affect the number of fires started. The experimental results also suggest that there is an amply safe margin in the choice of 0.3 cal $cm^{-2}s^{-1}$ as the maximum acceptable level of radiation used in the Building Regulations to determine separation of buildings.

The spontaneous ignition time can also be calculated from equation (5) assuming a fixed surface temperature criterion of 545°C. This correlating temperature for the larger specimens (7 cm and 15 cm square) is about the same as that given earlier for smaller specimens and the range of ignition times for which it is applicable has been extended to at least 130s. However, for the results of the smaller specimens, 5 cm square, analysed in this paper, there is a residual effect due to density similar to that found for pilot ignition for the same size of specimen which suggests that the area correction factor is associated with the density both for ignition time and for minimum intensity of ignition.

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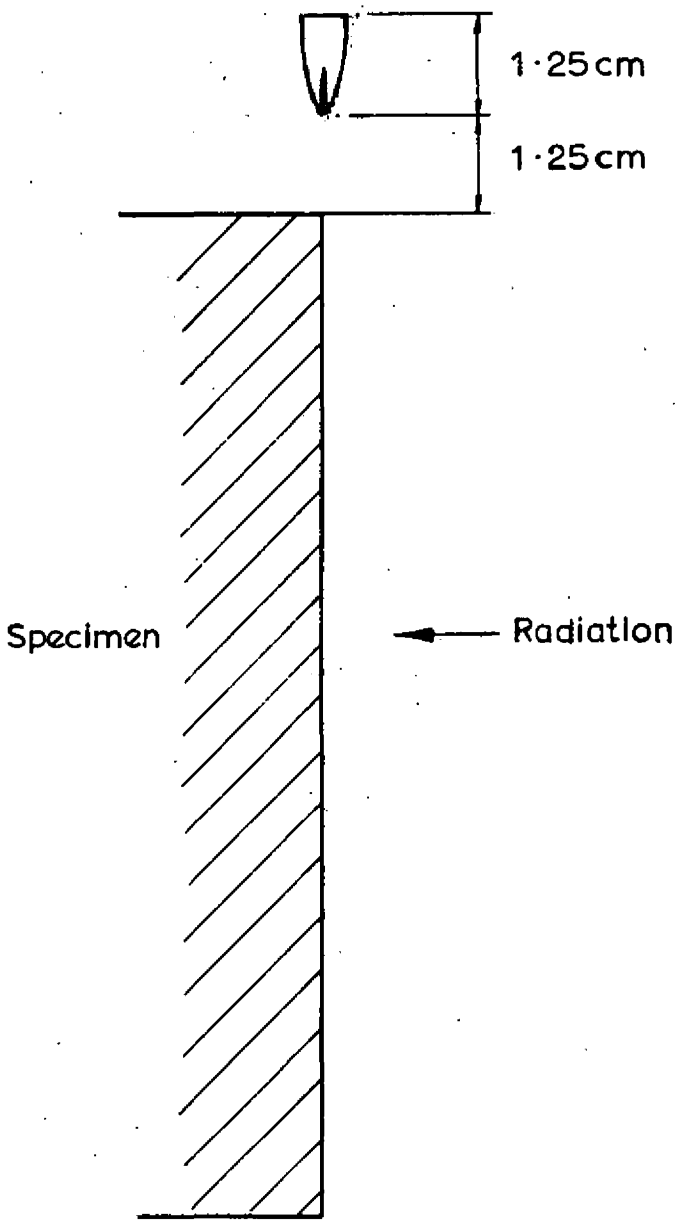


FIG.1. POSITION OF PILOT FLAME

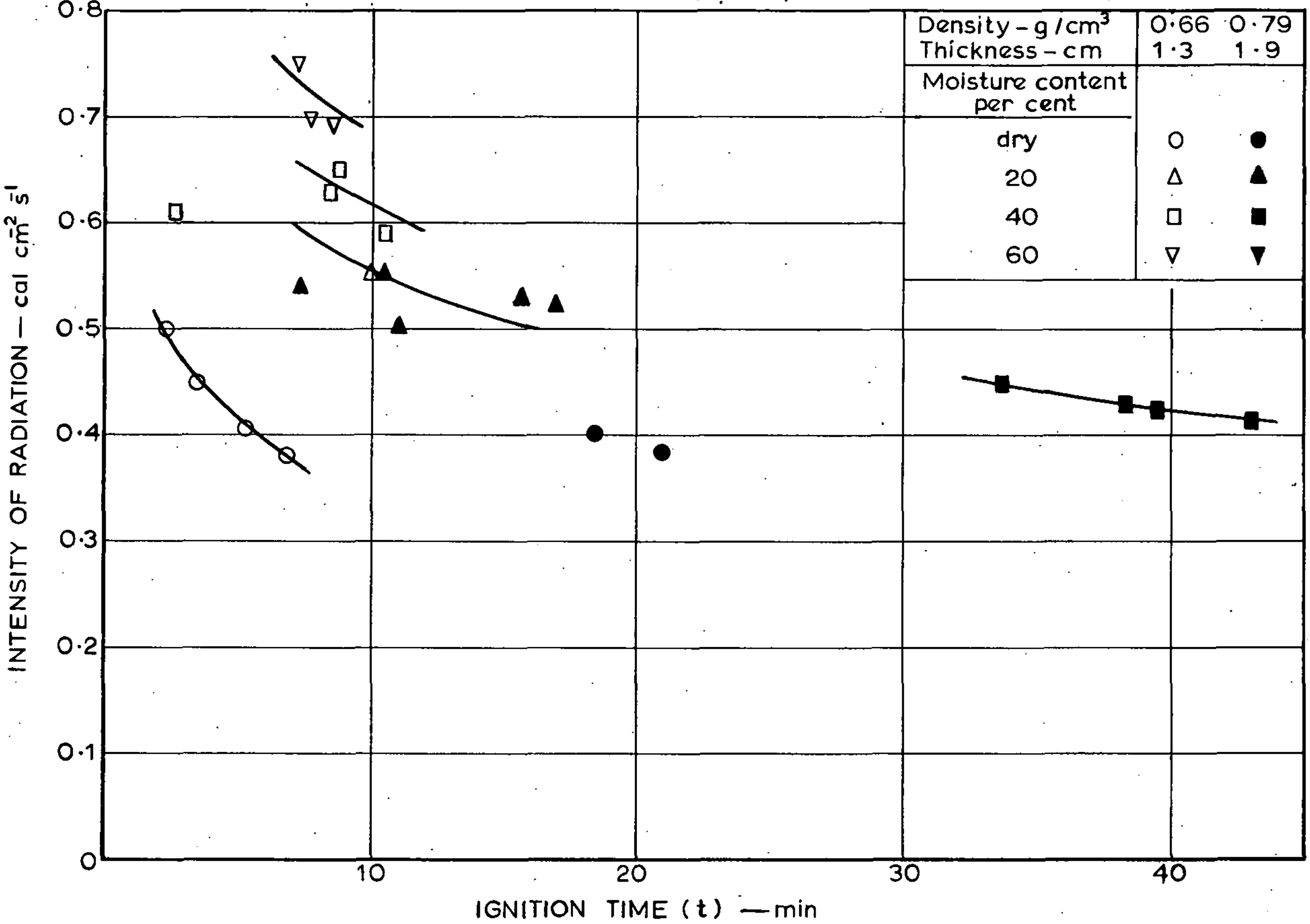


FIG.2a. PILOT IGNITION OF OAK

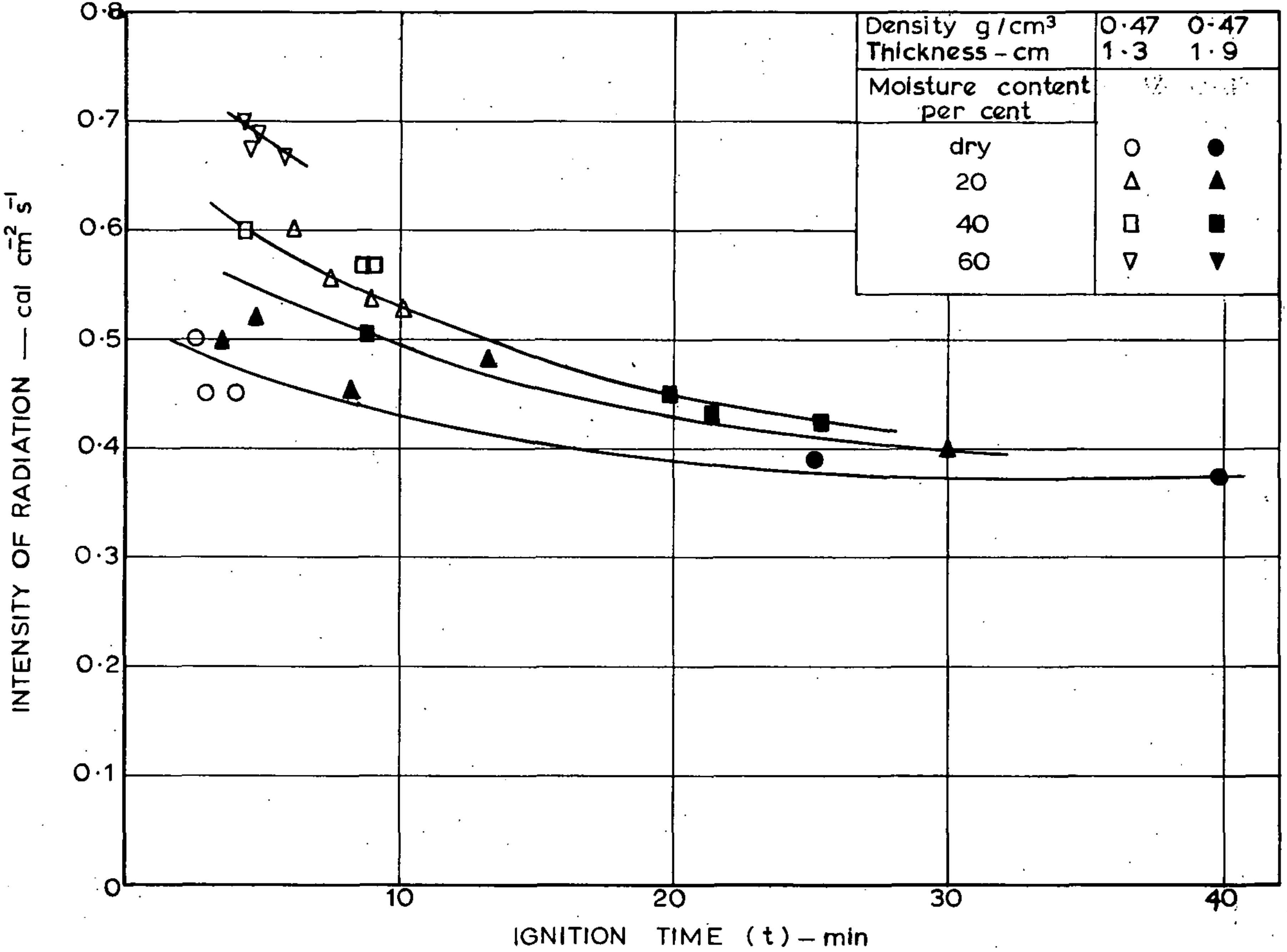


FIG. 2b. PILOT IGNITION OF EUROPEAN WHITEWOOD

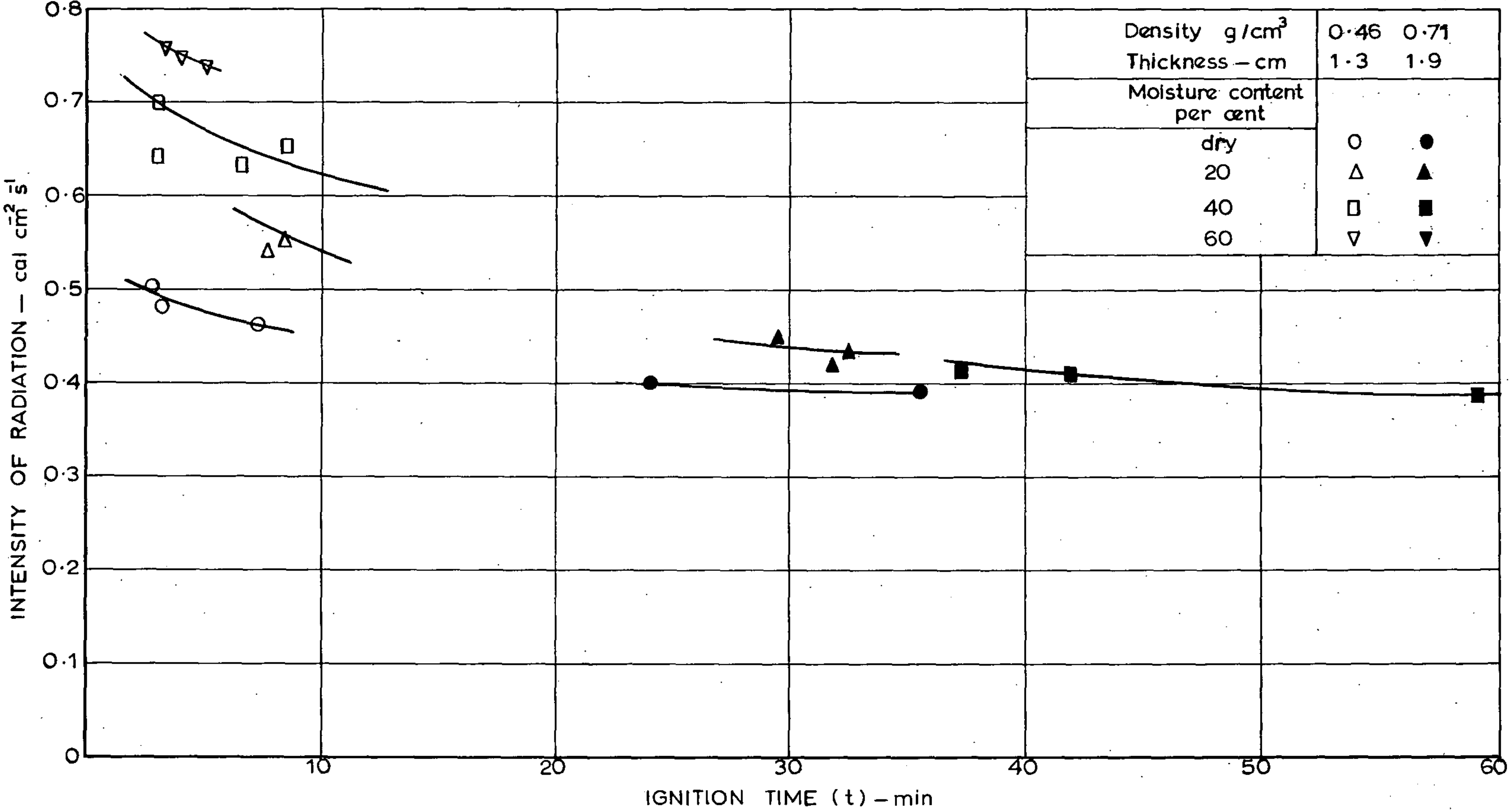


FIG. 2c. PILOT IGNITION OF COLUMBIAN PINE

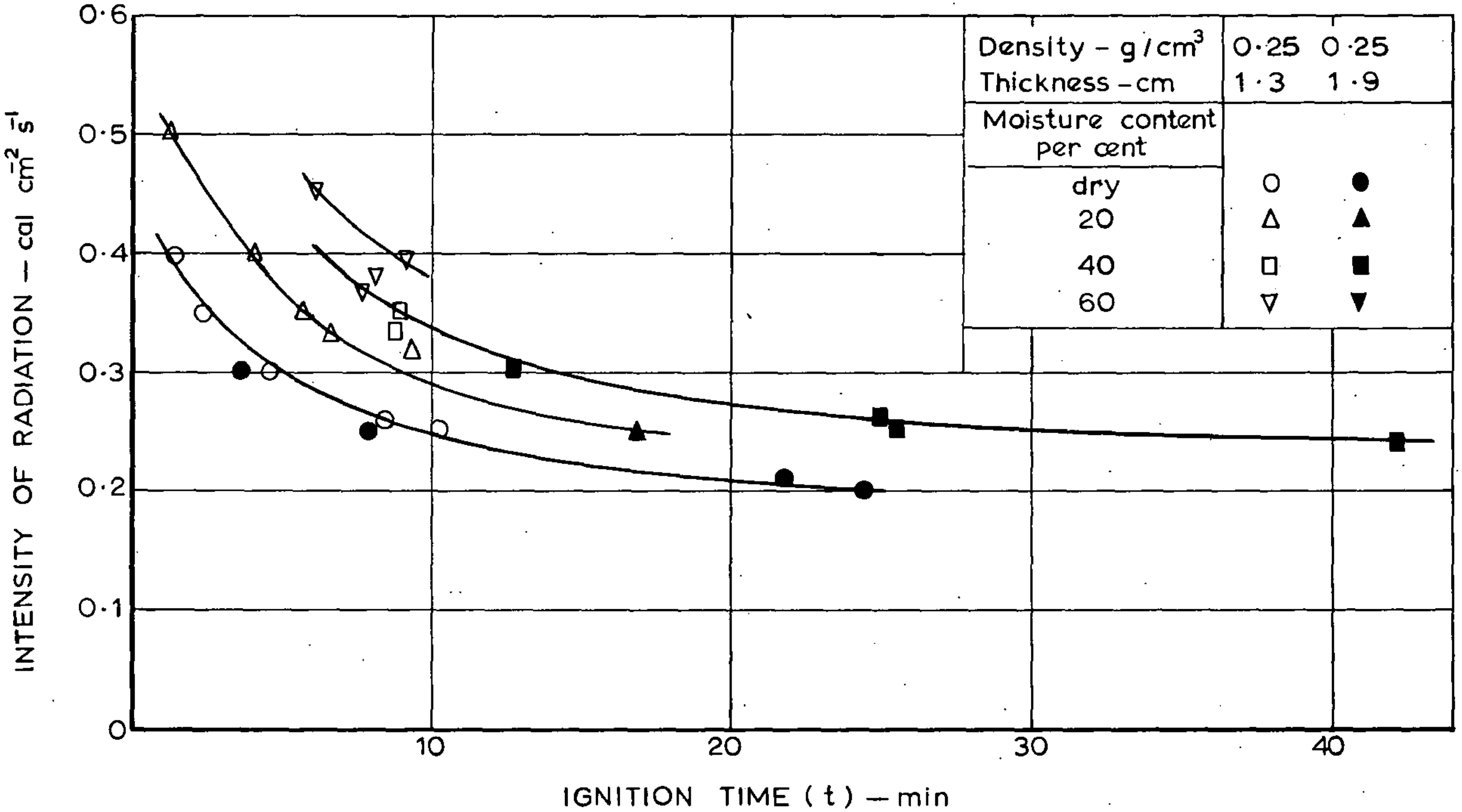


FIG.2d. PILOT IGNITION OF FIBRE INSULATING BOARD

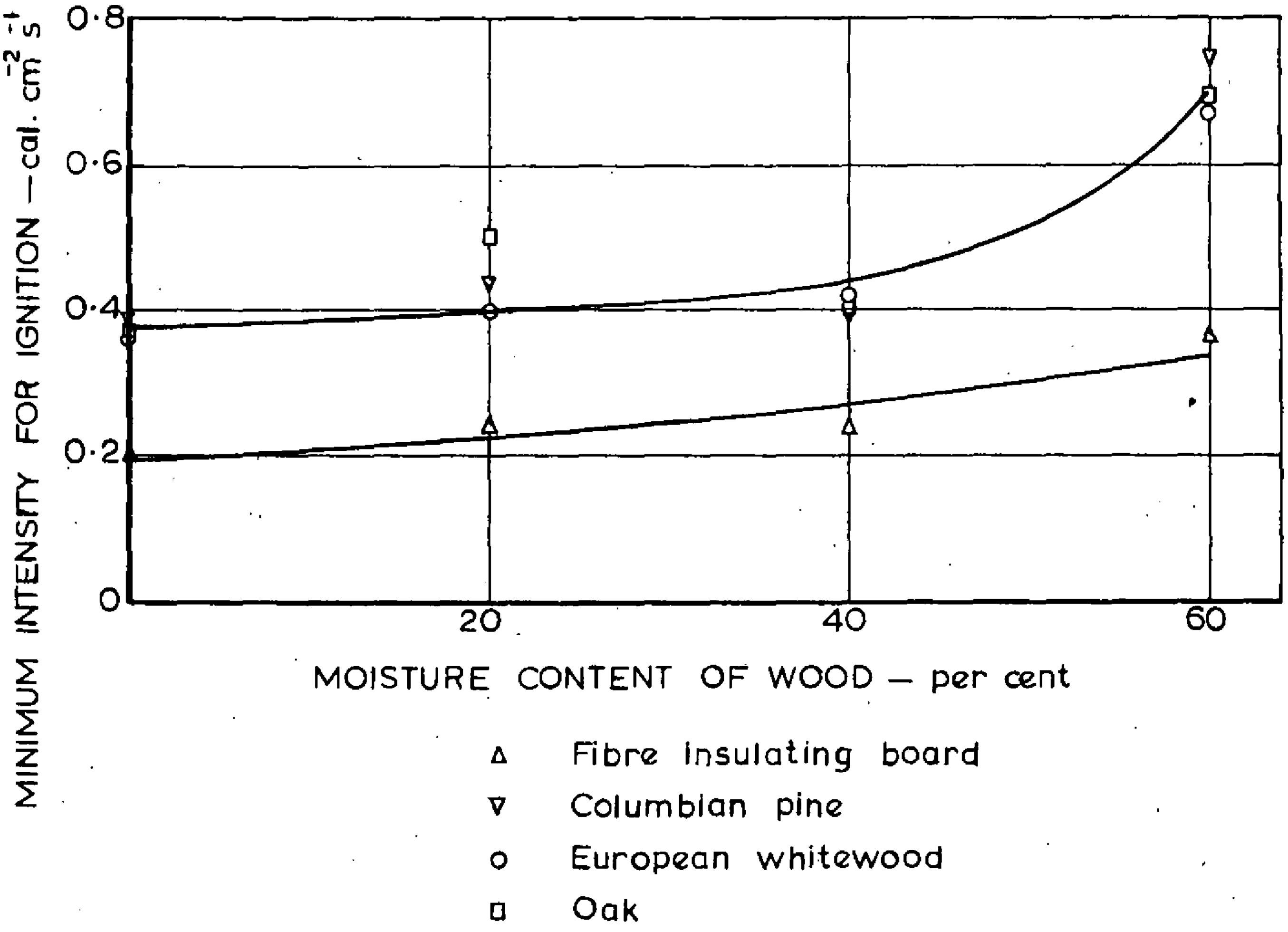


FIG.3. THE MINIMUM INTENSITY FOR PILOT IGNITION (SPECIMENS 7·6 cm SQUARE)

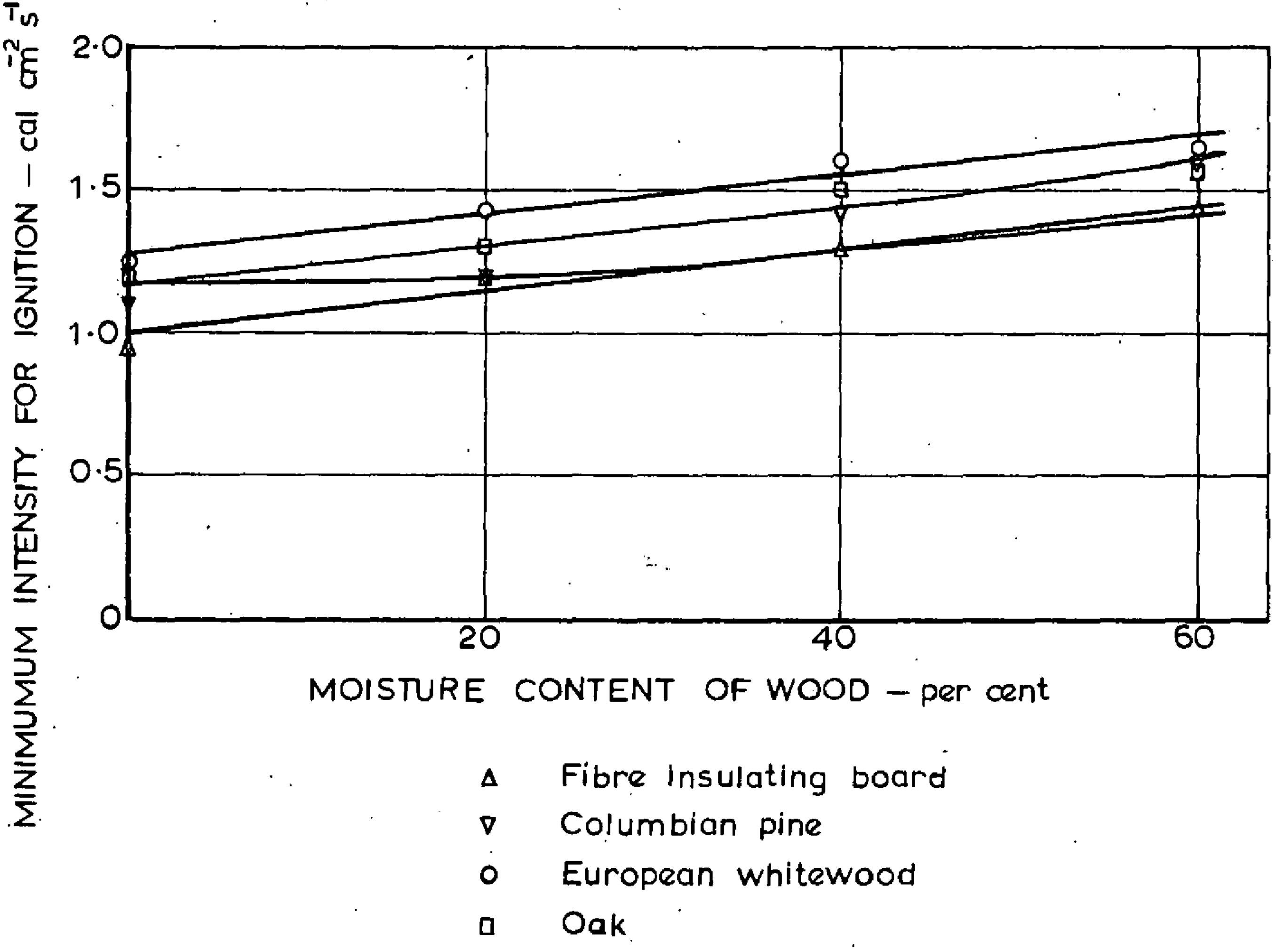
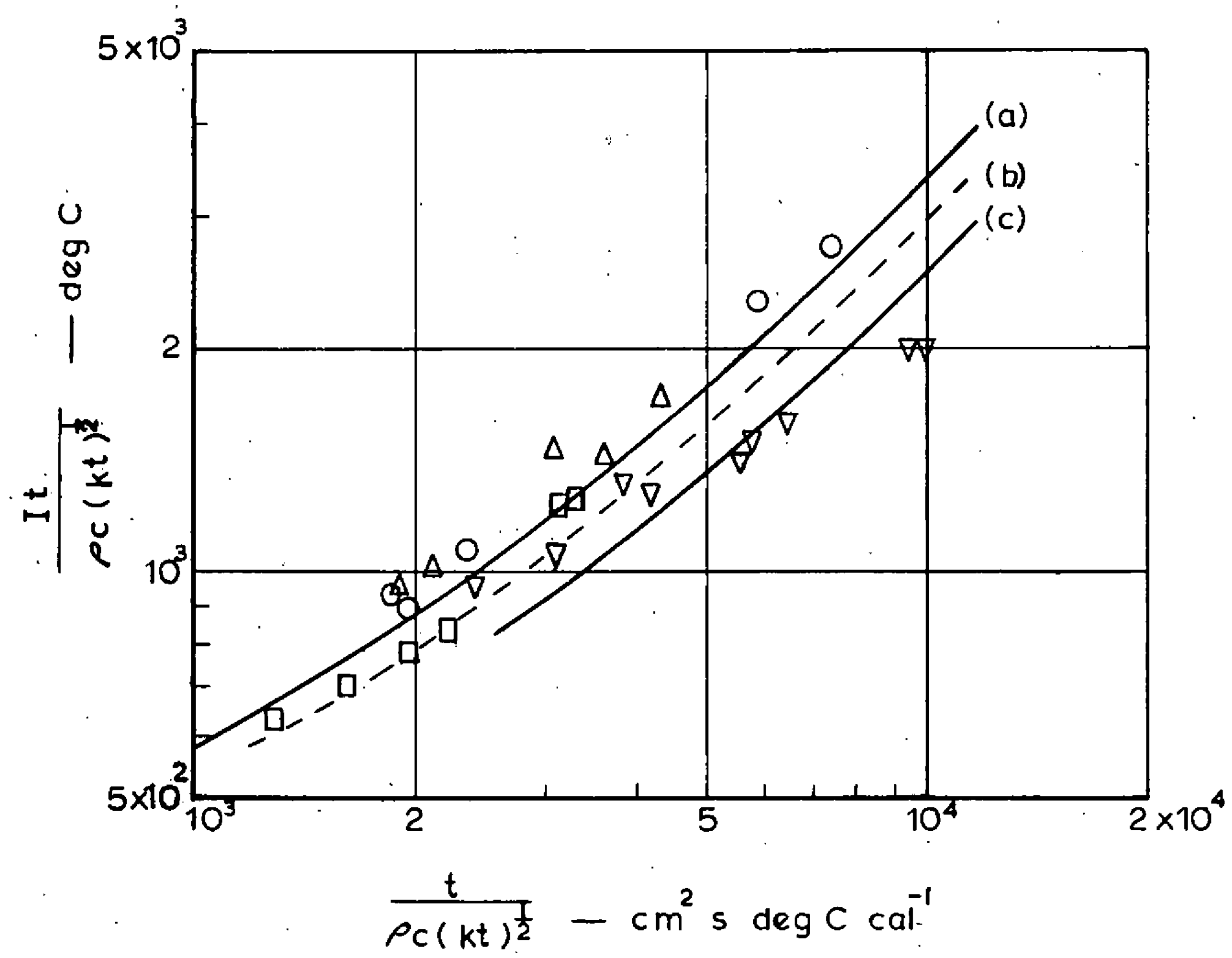


FIG.4. THE MINIMUM INTENSITY FOR SPONTANEOUS IGNITION (SPECIMENS 7·6 cm SQUARE)

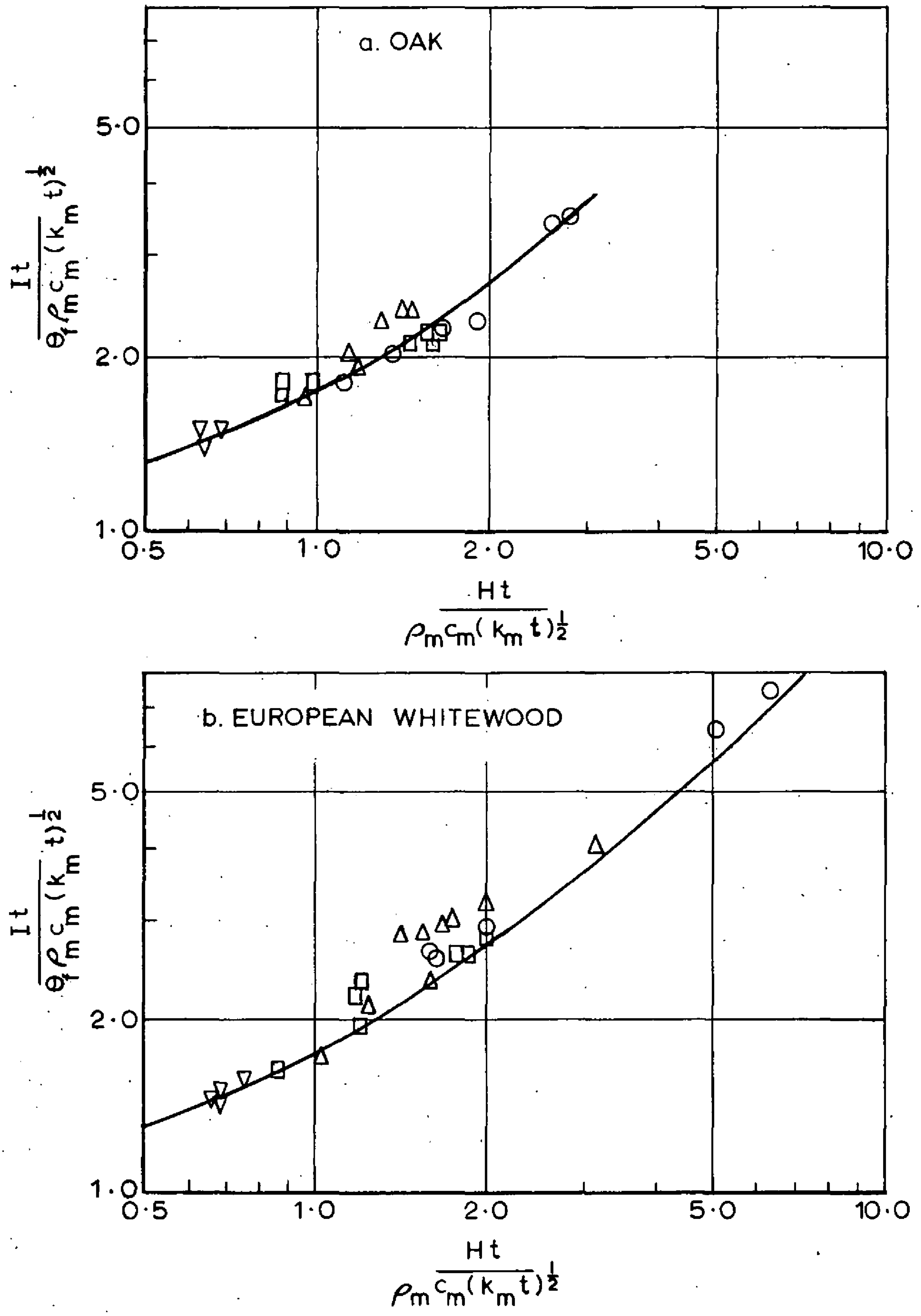


Curve	θ_f deg C	H cal cm^{-2} s^{-1} deg C^{-1}
(a)	360	$8 \cdot 6 \times 10^{-4}$
(b)	340	$8 \cdot 0 \times 10^{-4}$
(c)	310	$7 \cdot 4 \times 10^{-4}$

○	European whitewood
△	Columbian pine
□	Oak
▽	Fibre insulating board

Curves given by equation (5) with values assigned to θ_f and H

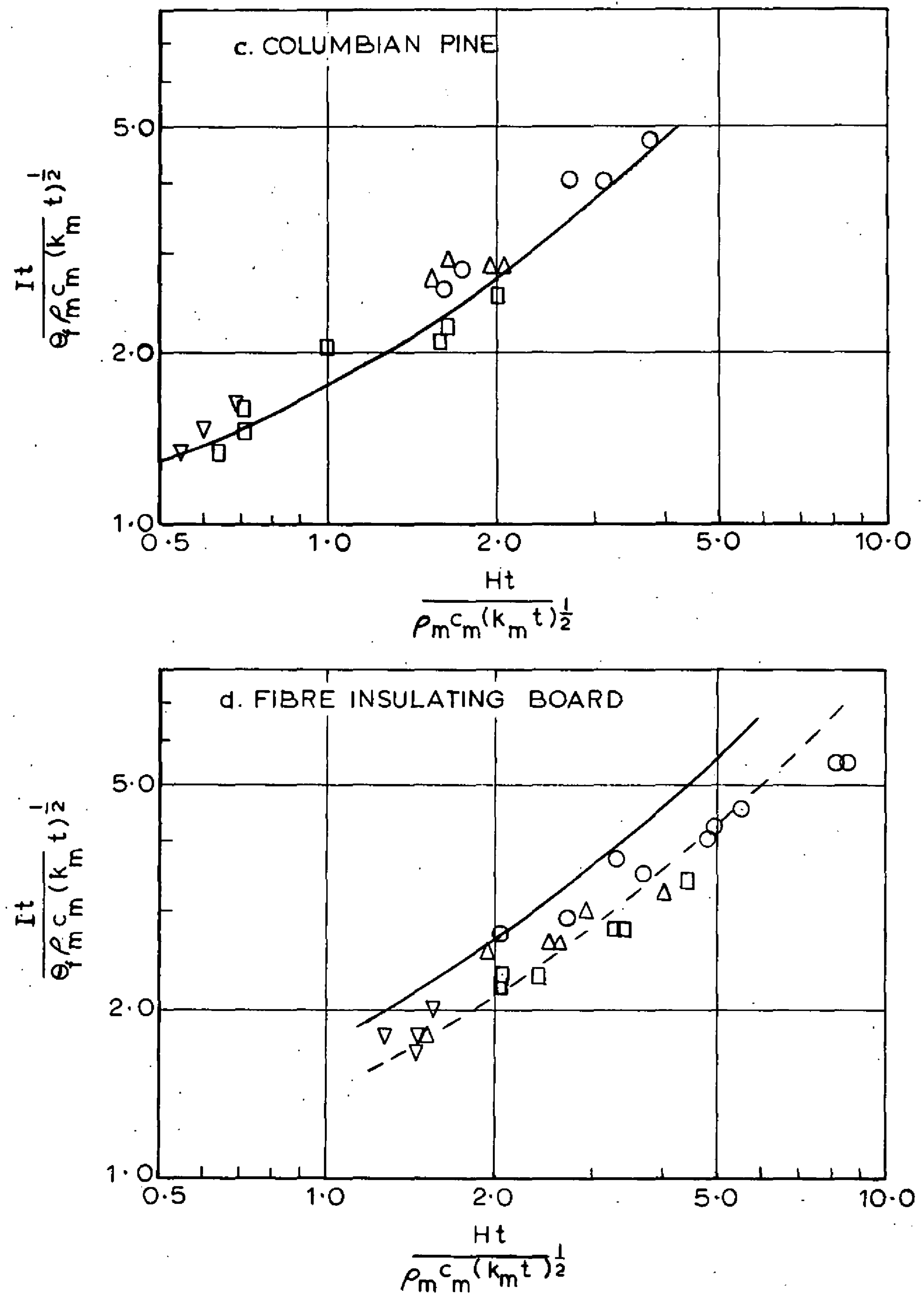
FIG.5. PILOT IGNITION OF DRY WOOD 7·6 cm SQUARE



Symbol	Moisture content per cent
○	dry
△	20
□	40
▽	60

Curve given by equation 5 with $\theta_f = 360$ deg C $H = 8{\cdot}6 \times 10^{-4}$ cal cm^{-2} s^{-1} deg C^{-1}

FIG.6A. CORRELATION OF PILOT IGNITION RESULTS FOR SPECIMENS 7·6 cm SQUARE

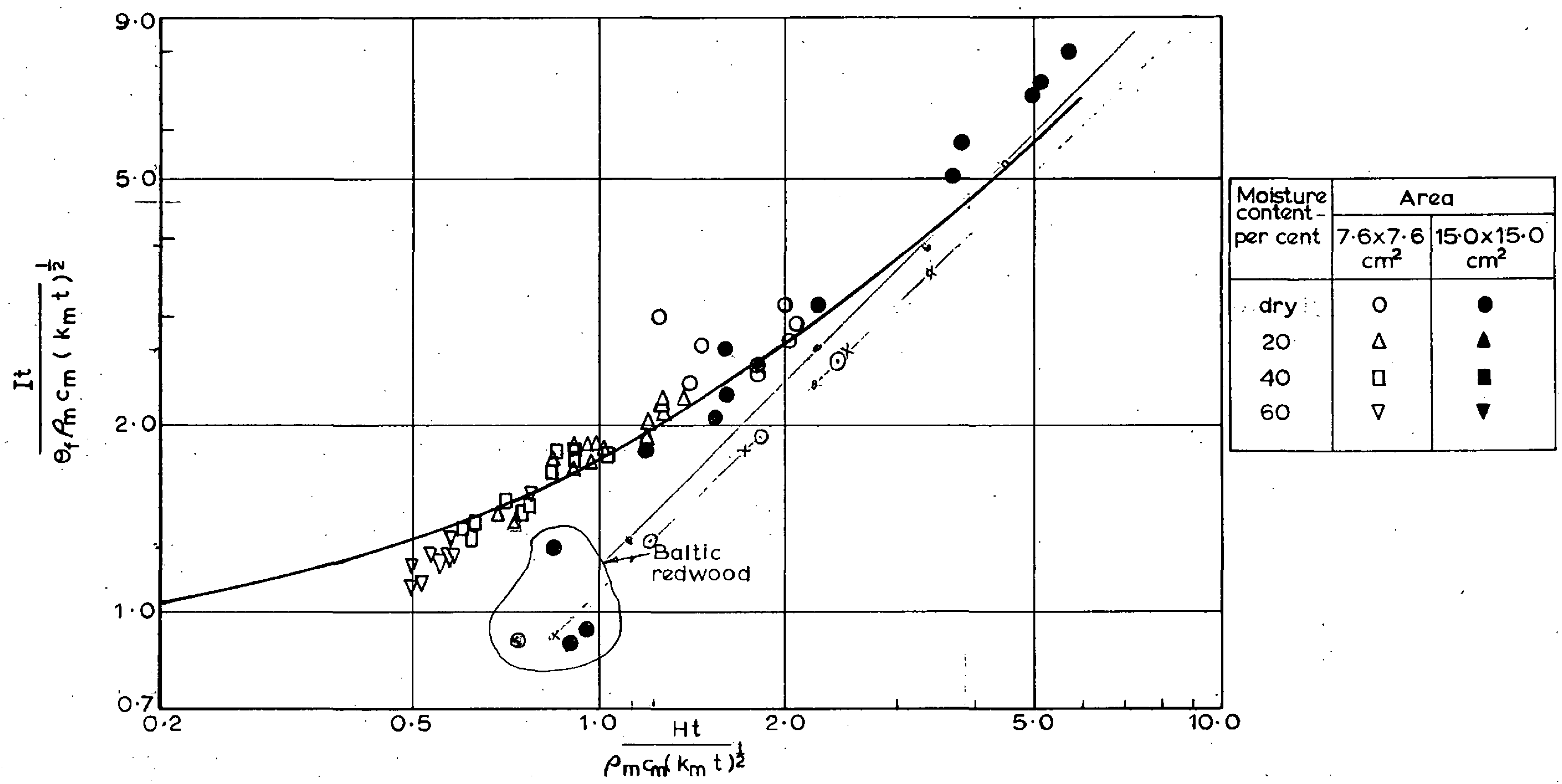


Symbol	Moisture content per cent
○	dry
△	20
□	40
▽	60

Curve given by equation 5 with $\theta_f = 360$ deg C $H = 8{\cdot}6 \times 10^{-4}$ cal cm^{-2} s^{-1} deg C^{-1}.

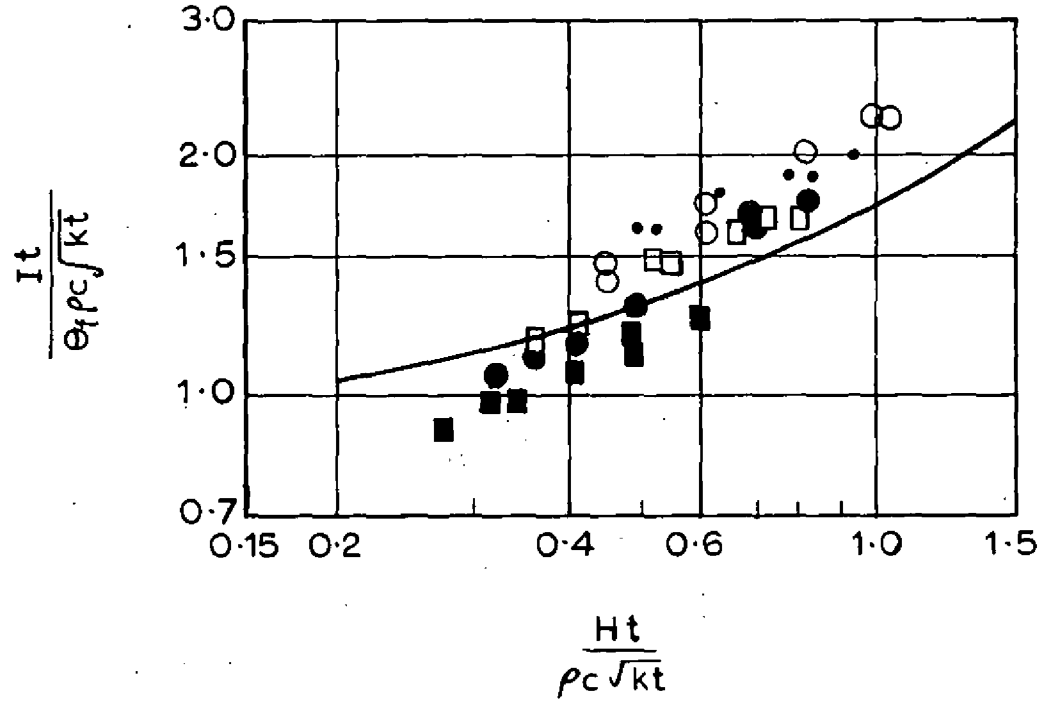
– – – – – – – – $\theta_f = 310$ deg C $H = 7{\cdot}4 \times 10^{-4}$ cal cm^{-2} s^{-1} deg C^{-1}

FIG.6B. CORRELATION OF PILOT IGNITION RESULTS FOR SPECIMENS 7·6 cm SQUARE

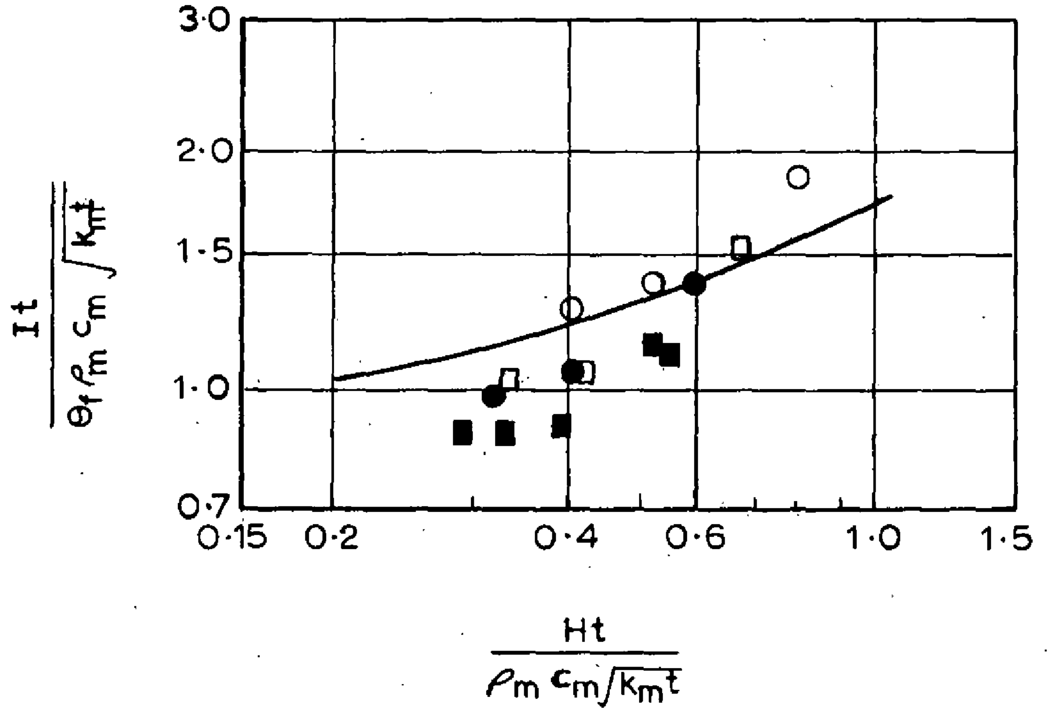


The curve is given by equation 5 with $\theta_f = 525$ deg C, $H = 1{\cdot}4 \times 10^{-3}$ cal cm^{-2} s^{-1} deg C^{-1}

FIG.7. SPONTANEOUS IGNITION OF EIGHT SPECIES OF WOOD 7·6cm SQUARE AND 15cm SQUARE SPECIMENS



(a) dry

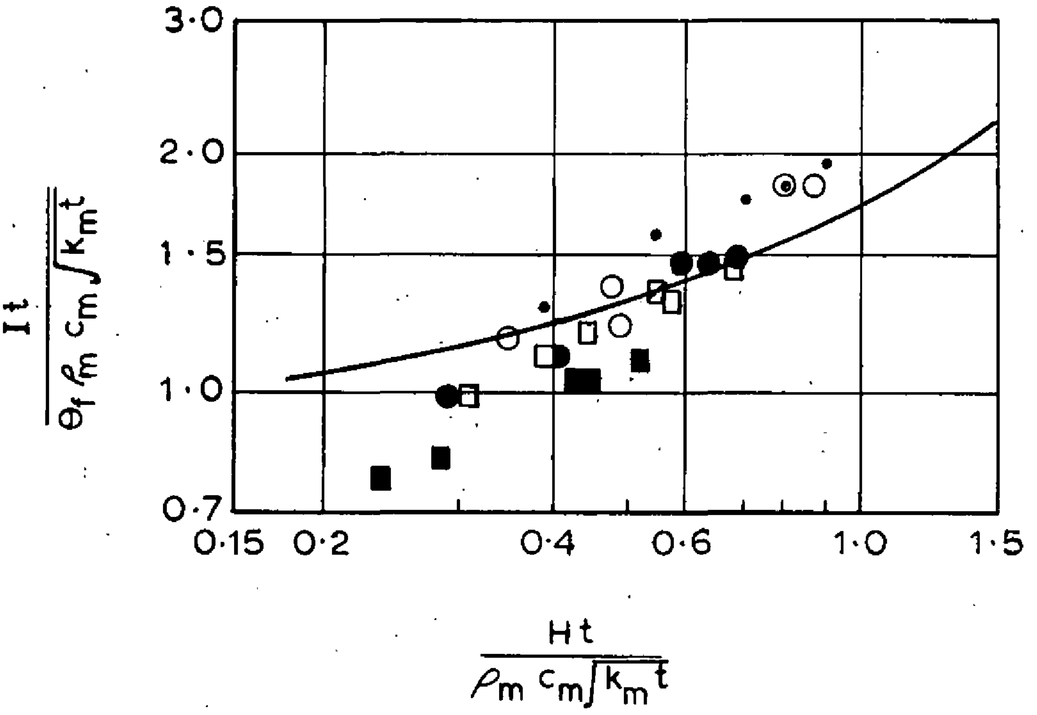


(b) Moisture content ≏ 5 per cent

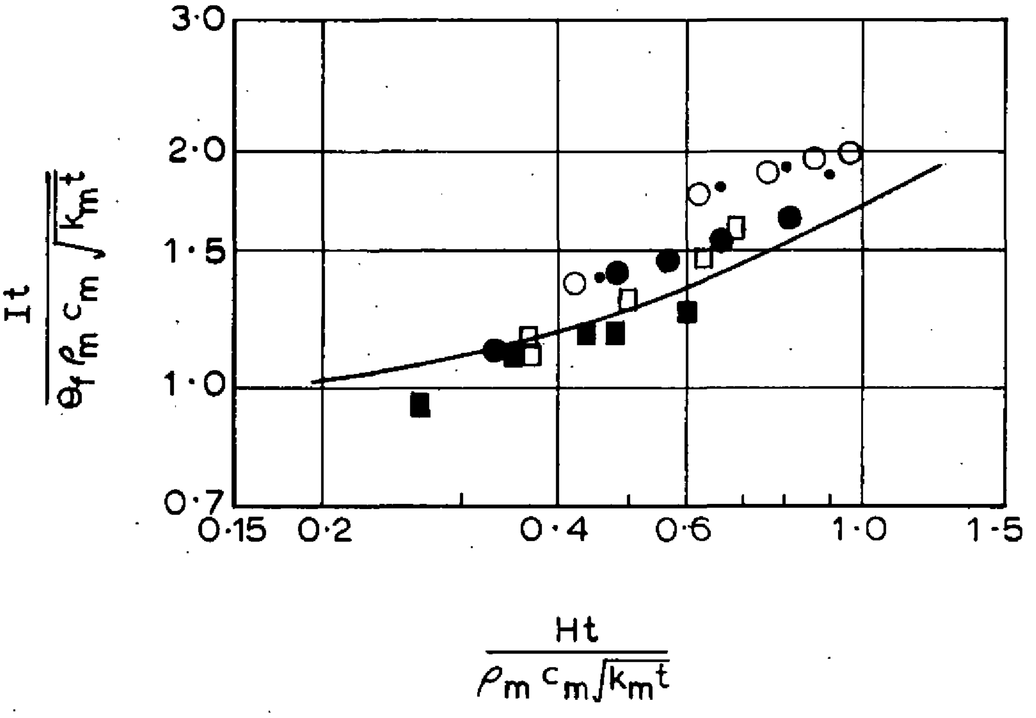
Curve is given by equation 5 with θ_f 525 deg C, $H = 1{\cdot}4 \times 10^{-3}$ cal cm^{-2} s^{-1} deg C^{-1}

Wood	Density (oven dry) gm/cm^3	Symbol
Fibre insulating board	0·24	•
Cedar	0·37	○
Mahogany	0·52	□
Columbian pine	0·55	●
Oak	0·66	■

FIG. 8A. SPONTANEOUS IGNITION OF 5 cm SQUARE SPECIMENS



(c) Moisture content ≃ 8 per cent



(d) Moisture content ≃ 12 per cent

For key see fig.8A.

Curve is given by equation 5 with θ_f 525 deg C $H = 1{\cdot}4 \times 10^{-3}$ cal cm^{-2} s^{-1} deg C^{-1}

FIG.8B. SPONTANEOUS IGNITION OF 5cm SQUARE SPECIMENS

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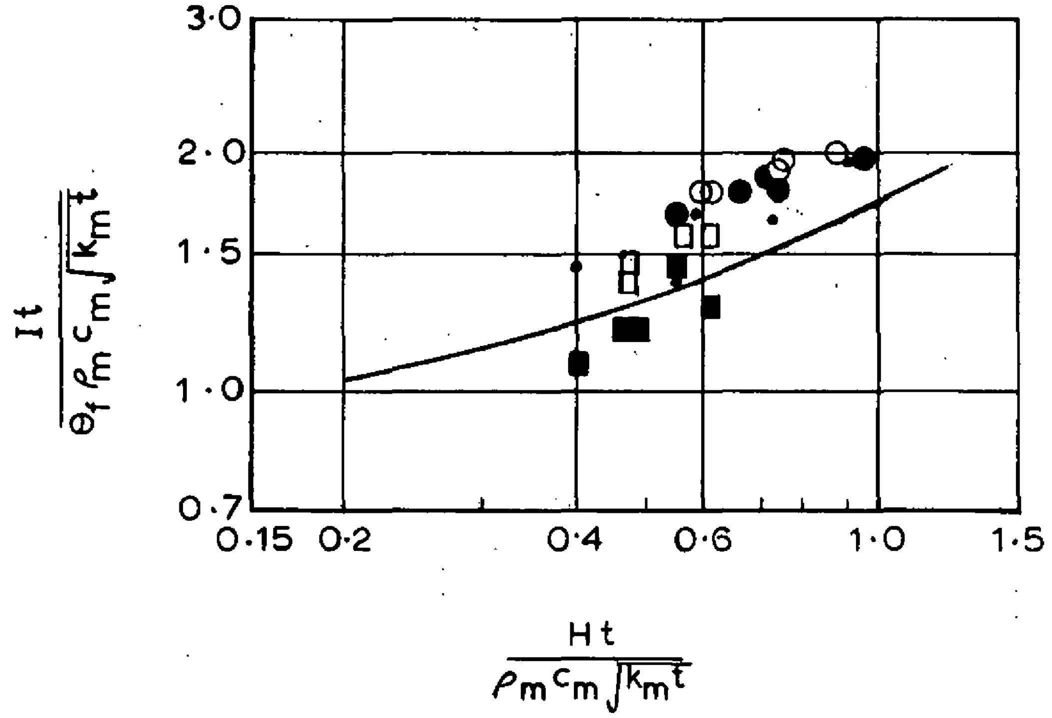
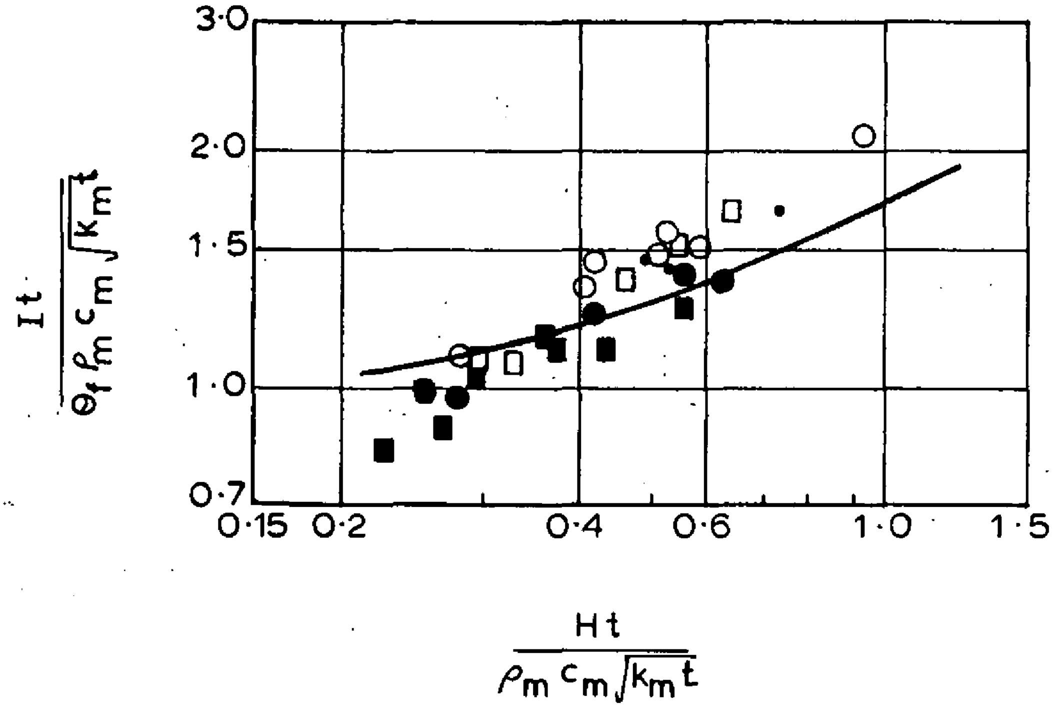


(e) Moisture content ≏ 15 per cent



(f) Moisture content ≏ 18 per cent

Fibre insulating board moisture content — 28 per cent

For key see fig. 8A.

Curve is given by equation 5 with θ_f 525 degC H = $1 \cdot 4 \times 10^{-3}$ cal cm^{-2} s^{-1} degC^{-1}

FIG. 8C. SPONTANEOUS IGNITION OF 5cm SQUARE SPECIMENS

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