Fire Research Note 553

# FIRE RESEARCH STATION

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

# FIRE RESEARCH NOTE

NO. 553

## SURFACE SPREAD OF FLAME OVER WOOD

by

D. L. SIMMS



June 1964

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F.R. Note No.553.

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## SUMMARY

When the predominating mode of heat transfer is by radiation, the rate at which flame spreads sideways across a vertical thick board, but not the furthest extent of spread, is independent of the height of the board.

By assuming that wood is an inert totally absorbing material, the time taken for a flame to reach a given position in spreading over the surface of boards of density varying from 0.13 to 1.00 $g/cm^3$ with a nominal moisture content of 15 per cent, has been correlated satisfactorily using simple heat transfer theory with intensities of radiation ranging from 0.5 to 1.0 cal $cm^{-2}$ $s^{-1}$. In this range, spread of flame occurs when the surface temperature reaches 300°C. Independent measurements of the surface temperature, at a point as the flame reaches it, have confirmed that this value is of the right order but suggest that there is a slight fall as the intensity of radiation falls. This fall becomes more rapid below intensities of about 0.5 cal $cm^{-2}$ $s^{-1}$ and a fixed temperature criterion no longer applies. Spread of flame continues to occur at intensities of radiation well below that expected from the correlating temperature (0.25 cal $cm^{-2}$ $s^{-1}$). The lowest intensity of radiation at which spread of flame is possible (the threshold intensity) is related to the density; the lighter the wood the lower the intensity at which spread can occur.

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## 1. Introduction

Pilot ignition of wood by radiation, where the volatiles produced from the heated surface region are ignited by a pilot flame in the volatile stream, and spontaneous ignition, where the volatiles ignite of their own volition, have been treated in a number of papers and the results have been reviewed elsewhere[1, 2].

Less attention has been paid to surface ignition by radiation, where the pilot flame is in contact with the surface and not in the volatile stream as in pilot ignition; with surface ignition, the whole surface does not immediately become involved in flame as in pilot and spontaneous ignition but instead the flame spreads over the surface by igniting the volatiles as they are produced. This kind of ignition is, however, in many ways, the most important of the three, since the rate and extent of flame spread over a surface will help to determine the rate of development of a fire in a compartment and out of doors. The heat required may be supplied in any or all of a number of ways, e.g. from the flames, from hot gases, by radiation from a distance source or from exothermic reactions within the solid.

The present paper reviews earlier work on surface ignition and describes some of the experimental and theoretical work on the subject carried out at the Fire Research Station.

## 2. Discussion of previous work

Bamford, Crank and Malan[3] irradiated specimens of Columbian Pine with the planed surface vertical and brought a match to the vertical surface of the specimen for about 2 seconds when they thought the surface was 'critically hot'. They noted that surface ignition, i.e. the spread of flame over the irradiated surface, occurred much sooner, and at much lower intensities of radiation, than pilot ignition*. They[3] found that the lowest intensity of radiation apparently necessary for surface ignition[3] to occur was about 0.025 cal $cm^{-2}$ $s^{-1}$. However, the rate and amount of heating from the match over 2 seconds (say, 0.5 cal $cm^{-2}$ $s^{-1}$) is at least comparable with the intensities of radiation from their experimental source (0-0.4 cal $cm^{-2}$ $s^{-1}$); so that the actual critical rate of heating must be higher than the value measured by them.

Webster[5] used a slightly different technique; he irradiated cedar shingles by a gas fired radiant panel using, as his igniting source, burning brands of hardboard of different weights placed on the surface of the wood. He found that a flame would not spread over cedar shingles from a burning brand weighing 100 g unless the intensity of radiation exceeded about 0.15 cal $cm^{-2}$ $s^{-1}$, whereas at even slightly higher intensities than this, a brand weighing 0.5 g was sufficient to start a spreading fire. Hird and Fischl[6], in their studies of flame spread in burning rooms, measured the intensity of radiation at the

*Bamford[4] refers to ignition by a pilot flame in the volatile stream as occurring when the surface is "Perilously hot".

furthest distance to which flames would spread along a 'deal' floor from a burning cupboard and found it to be about 0.1 cal $cm^{-2}$ $s^{-1}$.

Pickard, Simms and Walters[7] used a similar technique to that of Bamford, Crank and Malan[3] except that a small gas flame was used instead of a match in order to minimise the heating from the pilot source. However, at low intensities of radiation where ignition times were long the pilot flame often charred a pit round itself and was unable to spread; it was found to be impracticable to move the pilot flame into position at an appropriate time. A few results were, however, obtained from specimens of western red cedar and columbian pine; surface ignition was found to occur at intensities of radiation as low as 0.2 cal $cm^{-2}$ $s^{-1}$. The critical intensities of radiation for surface ignition, i.e. the theoretical intensity below which spread of flame would not occur, were estimated using the method devised by Lawson and Simms[8] and found to be about 0.1 cal $cm^{-2}$ $s^{-1}$ for both woods.

An alternative method, and one which does not have the difficulties associated with the pilot flame, is to irradiate the specimen at a rate which decreases from one end to the other; a comparatively large pilot flame is placed at the high intensity end of the board so that little charring occurs around it and the times taken for the flame to spread to given points along the board are noted. It has the additional advantage that the rate of spread of flame corresponding to a given intensity of radiation can be estimated. The British Standard test[9] for assessing the flame spread characteristics of materials is carried out in this way. Experiments[10, 11, 12] on different species of timber have been carried out at various times at the Fire Research Station, using this test[9] and a smaller scale version of it[11] and the results are presented and discussed in this paper. A preliminary analysis showed that the intensity of radiation at which flame spread ceases, decreased with decreasing density of the wood[13].

## 3. Experimental apparatus

The source of radiation is a 92 cm (3 ft) square panel with its radiating face vertical.

### 3.1. Standard test

A board 92 cm (36 in) long and 23 cm (9 in) high, is placed in the position shown in Fig.1. The intensity of radiation, $I_z$, falling on the board at any distance, $z$, from the panel is shown in Fig.2a; it is uniform in the vertical plane and the relation with distance is approximately exponential in form (Fig.2b), that is,

$$I_z = I_m e^{-nz} \qquad (1)$$

where $I_m$ is the maximum intensity falling on the surface and is approximately 1.0 cal $cm^{-2}$ $s^{-1}$

and $n$ is an attenuation factor $\simeq 0.025$ $cm^{-1}$.

A vertical pilot flame from a tube 1 cm ($\frac{3}{8}$ in) diameter about 15 cm (6 in) high, impinges on the high intensity end of the board. The times taken for the flame to spread along the board to given distances from the pilot flame, and the final distance of spread are noted.

### 3.2. Small scale test

In the small scale test, the linear dimensions are reduced by a factor of 3. The radiant panel is 31 cm (1 ft) square, whilst the standard specimens are 31 cm (12 in) long, 7.6 cm (3 in) high, and the pilot flame is about 5 cm (2 in) high. Equation (1) holds and the intensity distribution along the board has the same form as Fig.2a and b, but not the same magnitude. Repeated calibrations have shown that the method of calibration prescribed[9] is too imprecise; the actual intensity of radiation on the specimen may be as much as 20 per cent above or below the nominal value although the copper-asbestos monitoring disc may be at its prescribed value. Results cannot, therefore, be compared directly with those of the standard tests.

## 4. Experiments carried out at the Fire Research Station

### 4.1. Spread of flame

A number of experiments on the standard apparatus were carried out to find the variation of rate of spread of flame with timber of different species and densities[10] (Table 1). All specimens were at least 2 cm (0.75 in) thick; they were not conditioned but may be assumed to have a nominal moisture content of about 15 per cent. They were nailed to a holder constructed from asbestos millboard and their edges were sealed with sodium silicate paint[9]. The results are given in Fig.3.

Table 1

Woods tested
Specific heat taken as 0.7 cal $g^{-1}$ deg.$C^{-1}$, $C_m$[14]

| Wood | Number of specimens tested | Density ($\rho$) g/cm$^3$ | Thermal Conductivity $\perp$ to grain[15] (K) cal cm$^{-1}$ s$^{-1}$ deg.C$^{-1}$ |
|---|---|---|---|
| Balsa (Ochroma lagopus) | 1 | 0.13 | 1.4 |
| Western Red Cedar (Thuja plicata) | 1 | 0.42 | 3.2 |
| Redwood (Pinus sylvestris) | 1 | 0.42 | 3.2 |
| Gaboon (Aukoumea klaineana) | 3 | 0.50 | 3.9 |
| Poplar (Populus alba) | 3 | 0.55 | 4.2 |
| Columbian pine (1) (Pseudotsuga | 12 | 0.50 | 3.9 |
| taxifolia) (2) | 3 | 0.62 | 4.7 |
| Birch (plywood) (Betula spp) | 12 | 0.67 | 5.1 |
| Beech (1) | 3 | 0.67 | 5.1 |
| (Fagus sylvatica) (2) | 3 | 0.71 | 5.4 |
| Oak (1) | 3 | 0.71 | 5.4 |
| (Quercus spp) (2) | 6 | 0.88 | 6.7 |
| Greenheart (Ocotea rodioei) | 3 | 1.00 | 7.8 |

Tests were also carried out to find the effect of the height of the specimen on the rate of spread of flame(13, 14). These are listed in Table 2. No record of their densities is available; specimens were stored before test in a chamber and their moisture content was about 10 per cent. The height of the specimen holder was the same for all specimens, extending above the narrower ones so that convective heat losses were approximately constant.

Table 2

Woods tested and dimensions
(three specimens of each tested)

| Material | Standard Test (9) | Small scale Test (11) |
|---|---|---|
| | Height —cm | Height —cm |
| Columbian pine (Pseudotsuga taxifolia) | 23, 7.6<br>2.54, 1.3 | |
| Gaboon plywood (Aukoumea klaineana) | 23, 7.6, 5.1<br>2.54, 1.3 | |
| Fibre insulating board | 23, 7.6, 2.54 | |
| Western red cedar (Thuja plicata) | | 7.6, 5.1,<br>2.54, 1.27 |
| Poplar (Populus alba) | | " |
| Oak (Quercus spp) | | " |
| Mahogany (Khaya ivorensis) | | " |

4.2. Suface temperatures of irradiated specimens

In a further series of experiments (Table 3) Chromel-alumel thermocouples of 28 s.w.g. were fixed flush to the surface of the specimens with the thermo-junctions on the central horizontal axis placed at 5.1 cm intervals along the irradiated face. Their outputs were recorded automatically and as soon as the flame passed a thermocouple, readings were recorded from the next. The time taken for the flame to reach each thermocouple was recorded independently.

All specimens were 23 cm high and 61 cm long. They were heated in an oven at 60°C for three days (no oven large enough to dry the materials at a higher temperature was available) and then stored in an airtight box over phosphorus pentoxide. The average loss in weight was about 10 per cent and the moisture contents when tested was therefore unlikely to be greater than 5 per cent.

Table 3.

Woods tested

| Material | Density g/cm$^3$ |
|---|---|
| European Whitewood (Picea abies) | 0.49 |
| Oak (Quercus robur) | 0.52 |
| Columbian Pine (Pseudotsuga taxifolia) | 0.53 |
| Hardboard | 1.0 |

## 5. Experimental results and discussion

### 5.1. General

The movement of the flame front was irregular; normally the top of the flame front preceded the bottom, but tongues of flame often advanced some distance ahead of the main flame front; these irregularities were sometimes, but not invariably, associated with irregularities in the wood, e.g. knots. The distance-time relations which were recorded are the times at which the flame front passed the centre of the vertical line on the face. Bruce and Miniutti(16) noticed a similar variation in the movement of the flame-front using the small scale tunnel test and adopted the same procedure for recording results.

Flaming normally died right down soon after ignition, but flared up again very much later, presumably when the heat had penetrated to the rear surface and the mean temperature of the wood had reached 500°C(3)(2). This occurred well after the experiment was over.

### 5.2. Spread of flame

Results are given for the distance of spread at various times in Fig.3a-m, and presented in order of increasing intensity; in general, the lighter the wood the faster the rate of spread. The rate of spread appeared to be independent of the height of the specimen (Fig.4) but the furthest distance of spread depended markedly upon it (Fig.5a, b).

By plotting the intensity of radiation at the furthest distance to which flame will spread against the inverse of the corresponding height, $^1/L$, the intensity of radiation at which flame spread is just possible for a board of infinite height may be estimated by extrapolating to the zero value of $^1/L$, (Fig.6a, b). For practical purposes, the results for a board of 23 cm height and over are characteristic of a board of infinite height.

In experiments on spontaneous ignition(17), both the ignition time and the minimum intensity at which ignition occurred were found to increase with decreasing size of area irradiated. The increase in spontaneous ignition time was ascribed to the smaller size of the volatile plume which therefore cooled more quickly. With surface ignition the volatiles are absorbed directly into the advancing flame front; the size of the volatile plume is therefore irrelevant and little or no effect on surface ignition time and hence on the rate of spread of flame is to be expected. The increase in the minimum intensity for spontaneous ignition is ascribed to the limited supply of volatiles in the surface region becoming exhausted before the volatile/air mixture is hot enough and rich enough for ignition and a similar reason would explain the effect of height on the extent of spread; the smaller the height the smaller the supply of volatiles. However, these conclusions are only applicable to situations where the flame contributes only a small proportion of the heat required for ignition; they may not apply if the heat transfer from the flame is predominant or even significant. The heat transfer is then a function of the height of the board since this affects the size of the burning zone which controls the size of the flame and hence the heat transfer from it[18].

### 5.3. Temperature readings

Some difficulty was found in measuring the time at which the flame reached the thermo-junction and hence determining the ignition temperature. The irregular movement of the flame front often meant that the thermocouple wires became red-hot before the flame reached the junction itself and the flame front might remain near a junction, possibly being cooled by it, for some moments. The results were therefore rather scattered, but the temperature recorded fell from about 300°C at the hotter end, to about 250°C at the other for all the woods tested (Fig.7a–d).

Webster and Birtwistle[19] carried out a similar experiment using more elaborate apparatus; they placed thermocouples along the central horizontal axis of a sheet of hardboard at 2.54 cm (1 in) intervals along its vertical face and recorded the rise in temperature at each position and the variation in temperature distribution as the flame travelled across its surface (Fig.8). This also showed a progressive reduction in surface temperature with decreasing intensity, values of about 300°C being recorded at one end, and 200°C at the other.

## 6. Analysis of results

It has been shown elsewhere[17] that the surface temperature rise, $\theta$ at time, $t$, of thick wood, i.e. one for which there is no significant temperature rise of the rear surface, receiving heat on one face $I$ and losing heat by Newtonian cooling from that face, and assuming that the wood is chemically inert, opaque to radiation and with constant thermal properties, is given by

$$\frac{It}{\rho c (kt)^{\frac{1}{2}} \theta} = \frac{\beta}{1 - \exp \beta^2 \operatorname{erfc} \beta} \qquad (2)$$

where $\rho$ is the density

$c$ the specific heat

and $k$ the thermal diffusivity of the material, and

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

where H is the Newtonian cooling constant

and K is the thermal conductivity

$$\operatorname{erfc} \beta = \frac{2}{\sqrt{\pi}} \int_{\beta}^{\infty} e^{-\beta^2} \, d\beta$$

For both pilot(1) and spontaneous ignition(2,17) a fixed temperature criterion holds, i.e. the appropriate ignition time may be calculated assuming that ignition occurs when the irradiated surface reaches a fixed temperature, $\theta_F$, which is different for the two types of ignition and for different positions of the pilot flame. Although the measurements of section 4 (Fig.7) tend to show that the surface temperature at which flame spread occurs is not constant, the dimensionless parameters of equation (2) can still be used in the analysis of the results, provided the incomplete modulus $It/\rho c\,(kt)^{\frac{1}{2}}$ is used. One further assumption is necessary, that the intensity of radiation from the panel is always much larger than the sum of the heat contributed by the flame and the heat conducted laterally along the wood so that the rate of heat received by the surface can be identified with the intensity of radiation from the panel. The heat transfer from the flame is likely to be negligible, especially near the hot end, since the irradiated face of the board is vertical and little convected heat reaches the adjacent surface, and the flames are extremely thin and of low emissivity so that radiated heat transfer is also small. The lateral heat conduction is negligible at the higher intensities of radiation (Appendix I). If these heating effects can be neglected and spread of flame considered to be a series of discrete ignitions, the time taken to ignite at any point is independent of conditions elsewhere on the board and only controlled by the physical quantities in equation (2)

The presence of moisture increases the ignition time. It is shown elsewhere(14), that, if the values of the thermal properties, $K_m$, $\rho_m$ appropriate to the given moisture content are used and the value of the specific heat adjusted to allow for the latent heat of evaporation and the heat of wetting, there is little or no residual effect due to moisture. For this reason, the thermal constants given in Table I and used in equation (2) are for specimens having a nominal moisture content of 15 per cent. A first approximation for $\theta_F$ may be obtained from the mean values of

$$\frac{It}{\rho_m c_m (k_m t)^{\frac{1}{2}} \theta_F} \quad \text{when} \quad \frac{Ht}{\rho_m c_m (k_m t)^{\frac{1}{2}}}$$

tends to zero, since

$$\frac{It}{\rho_m c_m (k_m t)^{\frac{1}{2}} \theta_F} \rightarrow \frac{\pi^{\frac{1}{2}}}{2} \qquad (3)$$

An appropriate value for the Newtonian cooling constant, H, for that temperature range may then be obtained. The value of $\theta_F$ is then adjusted to give the best fit between the experimental points (Fig.9) and equation (2).

A relation of the form of equation (2) holds for values of $\frac{Ht}{\rho_m c_m (k_m t)^{\frac{1}{2}}}$ less than say 1.0, and, in this region, a reasonably good fit is obtained for a value of $\theta_F$ of 300°C. This value is in close agreement with the measured values (Fig.7) and with values given elsewhere[16,20]. This is also the temperature at which most cellulosic materials begin to decompose rapidly[21] and this suggests that spread of flame over a surface is possible as soon as volatiles are being produced more rapidly than a given critical rate.

The rate of production of volatiles is heavily dependent on temperature so that at comparatively high rates of heating ($>$ 0.5 cal $cm^{-2}$ $s^{-1}$) and consequently, comparatively high rates of temperature rise, the temperature at which the rate becomes critical may be taken to be constant, i.e. when the surface temperature rises to about 300°C.

For values of $\frac{Ht}{\rho_m c_m (k_m t)^{\frac{1}{2}} \theta_F} < 1.0$, corresponding to intensities of radiation below about 0.5 cal $cm^{-2}$ $s^{-1}$ and to times of irradiation greater than 500s, the value of $\frac{It}{\rho_m c_m (k_m t)^{\frac{1}{2}} \theta_F}$ ceases to increase and usually diminishes; this suggests that the ignition temperature is also falling in a way similar to that found in Figs.7 and 8. The reasons for this are uncertain. The heat transfer from the flames and the heat conducted longitudinally through the wood may be comparable with the intensity of radiation from the panel. Additionally, the wood is at or above 200°C for long enough for self-heating of cellulose to be significant[21,22]. This latter explanation is supported by similar experiments on the pilot ignition of fibre insulating board at similar intensities of radiation[1] and below intensities of radiation of about 0.4 cal $cm^{-2}$ $s^{-1}$, values of $\frac{It}{\rho_m c_m (k_m t)^{\frac{1}{2}} \theta_F}$ for pilot ignition ceased to increase and fibre insulating board continued to ignite at intensities of radiation as low as 0.2 cal $cm^{-2}$ $s^{-1}$ which is well below the critical intensity for wood of 0.3 cal $cm^{-2}$ $s^{-1}$[8]. On the other hand a recent extensive series of experiments on the pilot ignition of vertical specimens of wood of different species in front of a radiation panel with irradiation times as long as those used in the present experiments have shown little or no effect due to self-heating[23].

The critical intensity of irradiation, $I_o$, at which ignition is theoretically just possible is, in effect, the rate at which heat is lost at equilibrium from the surface at the temperature calculated[8], that is,

$$I_o = H\theta_F \qquad (4)$$

Since H is about $7.5 \times 10^{-4}$ cal $cm^{-2}$ $s^{-1}$ deg.$C^{-1}$ and $\theta_F$ is 300°, the value of $I_o$ for surface ignition is therefore about 0.25 cal $cm^{-2}$ $s^{-1}$. However, spread of flame may occur at intensities of radiation well below this; the lowest level at which spread is just possible (the threshold intensity) depends on the density of the wood and may well be as low as 0.1 cal $cm^{-2}$ $s^{-1}$ for a wood as light as balsa and even lower for fibre insulating board (0.03 cal $cm^{-2}$ $s^{-1}$). These values determined by these experiments are in fair agreement with those found earlier using other methods of measurements(3,5,6,7).

## 7. Conclusions

Where the heat supplied is predominantly from an external source the rate of spread of flame across a vertical surface does not depend upon the height of the board, but the extent to which it spreads decreases markedly with decreasing width, if the width is less than about 25 cm.

For intensities of radiation of about 0.5 cal $cm^{-2}$ $s^{-1}$, spread of flame over wood, of approximately 15 per cent moisture content, may be assumed to occur when the surface reaches a fixed temperature of about 325°C. This temperature is in the range where the production of volatiles becomes relatively rapid and suggests that the criterion for spread of flame is that a critical rate of evolution of volatiles shall be exceeded. Below a rate of heating of about 0.5 cal $cm^{-2}$ $s^{-1}$ a fixed surface temperature criterion cannot be used, and flame spread occurs at intensities of radiation below the nominal critical intensity of 0.25 cal $cm^{-2}$ $s^{-1}$ calculated from the correlating temperature; the reasons for this are uncertain. The least intensity of irradiation at which flame spread can occur may be as low as 0.1 cal $cm^{-2}$ $s^{-1}$ for a light wood like balsa and even lower for fibre insulating board. These values set the lower limits for the rate of heating at which flame spread is likely both within a compartment and out-of-doors.

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Acknowledgements

The author would like to thank (posthumously alas) Mr. C. T. Webster for his assistance in tracing the experimental records and Messrs. R. G. S. Caplin and M. Spyer for performing the calculations.

APPENDIX I

Estimate of lateral heat conduction in surface region.

Inserting equation (1) in equation (2) gives

$$\theta_z = (1 - \exp \beta^2 \operatorname{erfc} \beta) \frac{I_m \exp(-nz)}{H} \qquad (A.1)$$

If it be assumed, as a first approximation, that the surface temperature rise, $\theta_z$ at any distance $z$ from the hot end of the board is independent of conditions at neighbouring points, $z - dz$, and $z + dz$, then the thermal gradient, $K \frac{d\theta z}{dz}$, along the surface of the board is given by

$$K \frac{d\theta z}{dz} = \frac{nK}{H} I_m e^{-nz} (1 - \exp \beta^2 \operatorname{erfc} \beta) \qquad (A.2)$$

Reinserting equation (1) and (A.1) in equation (A.2) gives

$$K \frac{d\theta z}{dz} = n K \theta \qquad (A.3)$$

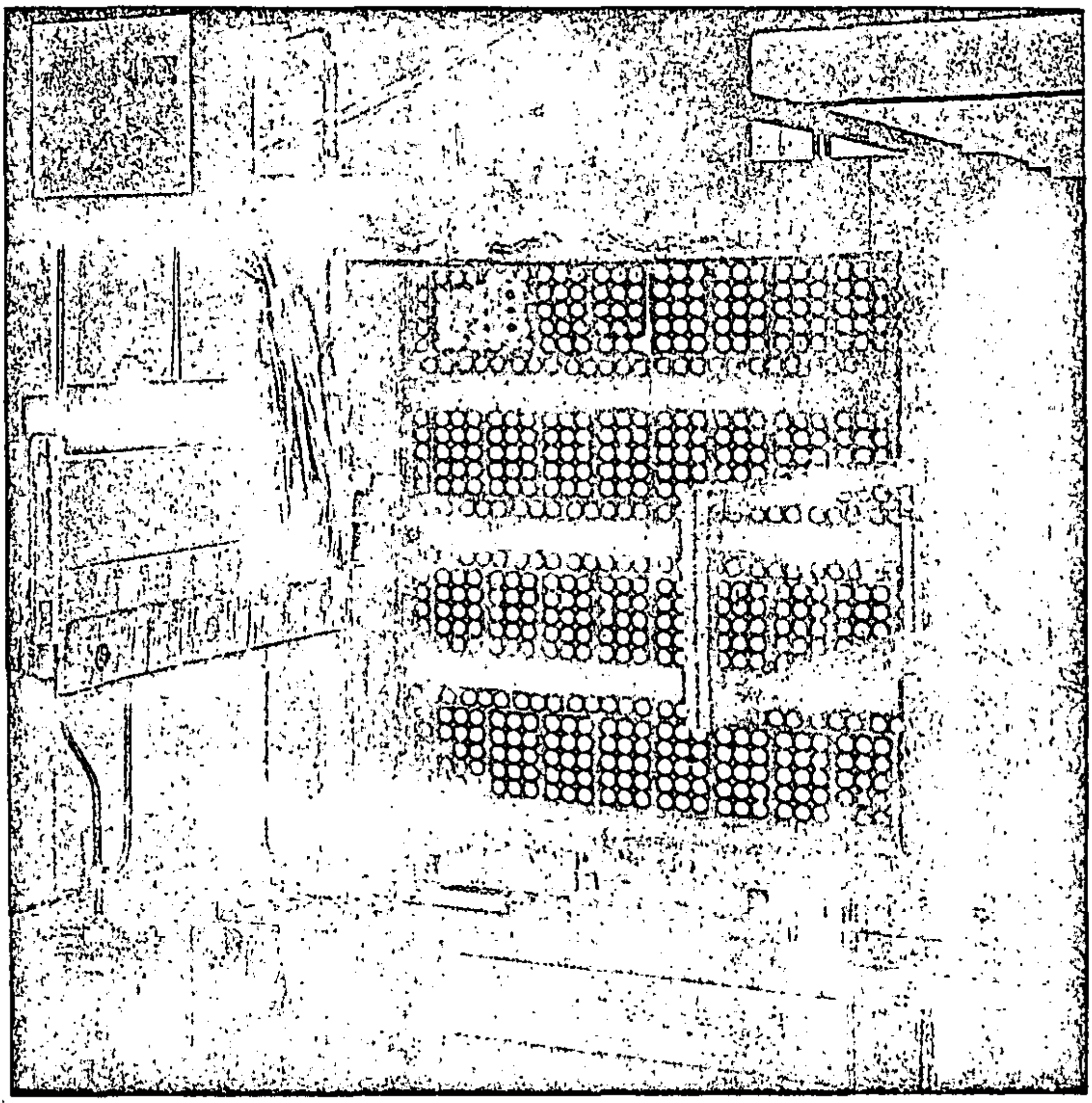
Inserting values for $n$, $K$ and $\theta$ gives for greenheart (Table 1)

$$K \frac{d\theta z}{dz} = 6 \times 10^{-2} \text{ cal cm}^{-2} \text{ s}^{-1}$$

and for balsa (Table I)

$$K \frac{d\theta z}{dz} = 1.5 \times 10^{-2} \text{ cal cm}^{-2} \text{ s}^{-1}$$

Both these values are always less than the least incident intensity of radiation at which flame spread occurs (the ratio is about $\frac{1}{3}$ for greenheart and $1/6$ for balsa). This justifies the original assumption that lateral heat conduction may be neglected at the higher rates of heating. However, the breakdown of the correlation at intensities of radiation below about 0.5 cal $cm^{-2}$ $s^{-1}$, and the consequent spread of flame below the calculated critical intensity of 0.25 cal $cm^{-2}$ $s^{-1}$ may be due in part to lateral conduction.



ARRANGEMENT OF THE APPARATUS SHOWING
SPECIMEN IN POSITION

FIG. 1

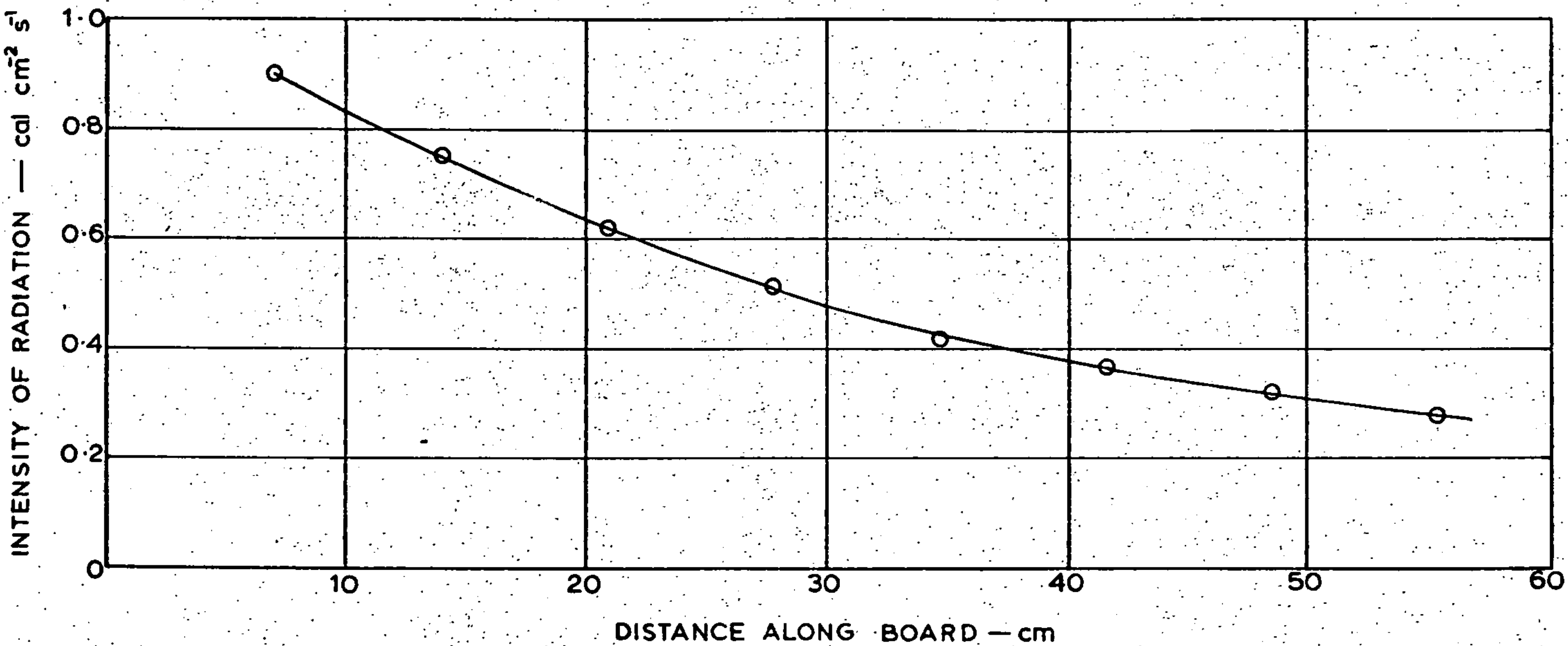



FIG. 2a. INTENSITY OF RADIATION FALLING ON SPECIMEN (STANDARD APPARATUS)

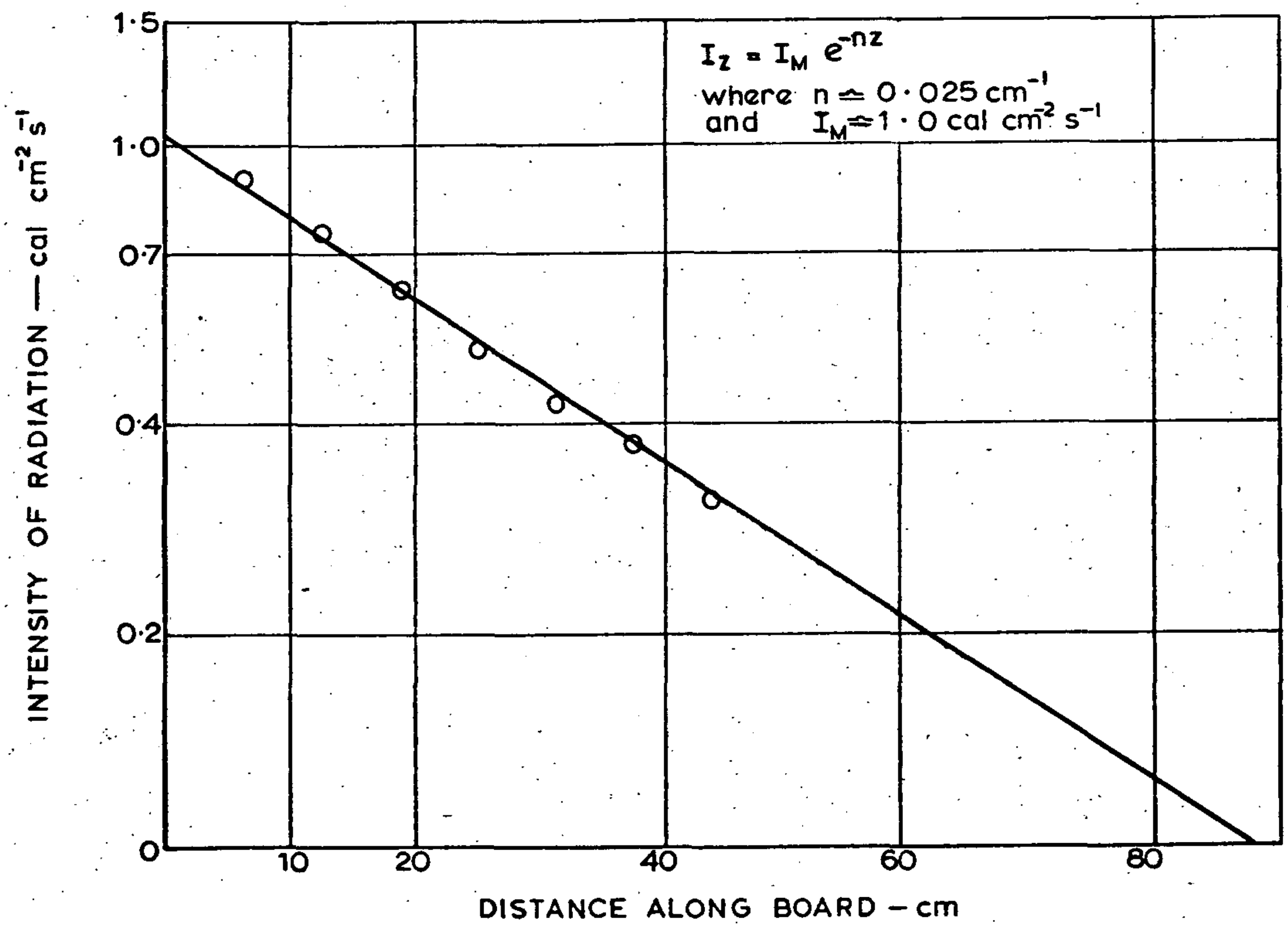



FIG. 2b. INTENSITY OF RADIATION FALLING ON SPECIMEN

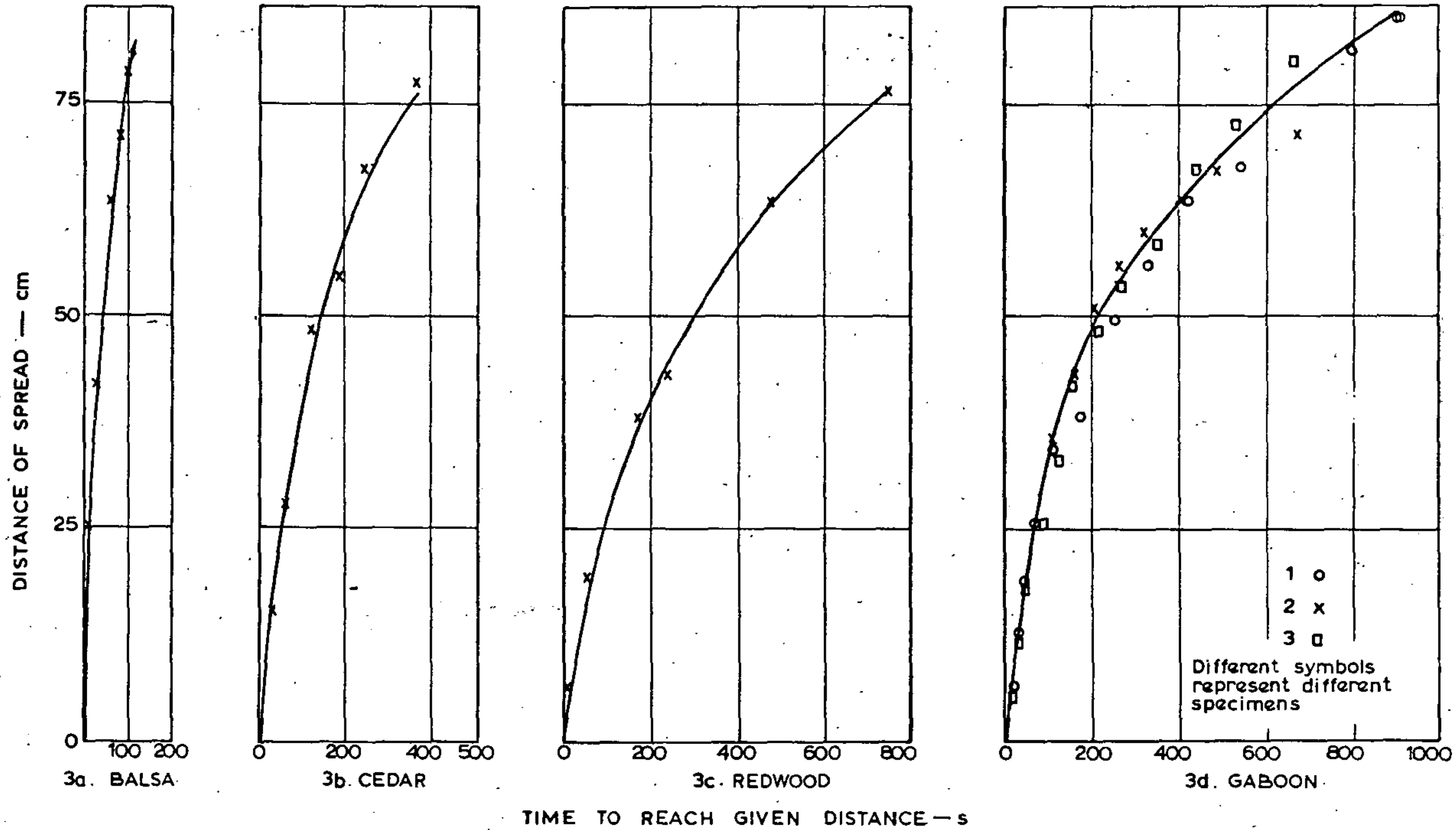



FIG.3a, b, c & d. SPREAD OF FLAME ON BALSA, CEDAR, REDWOOD & GABOON

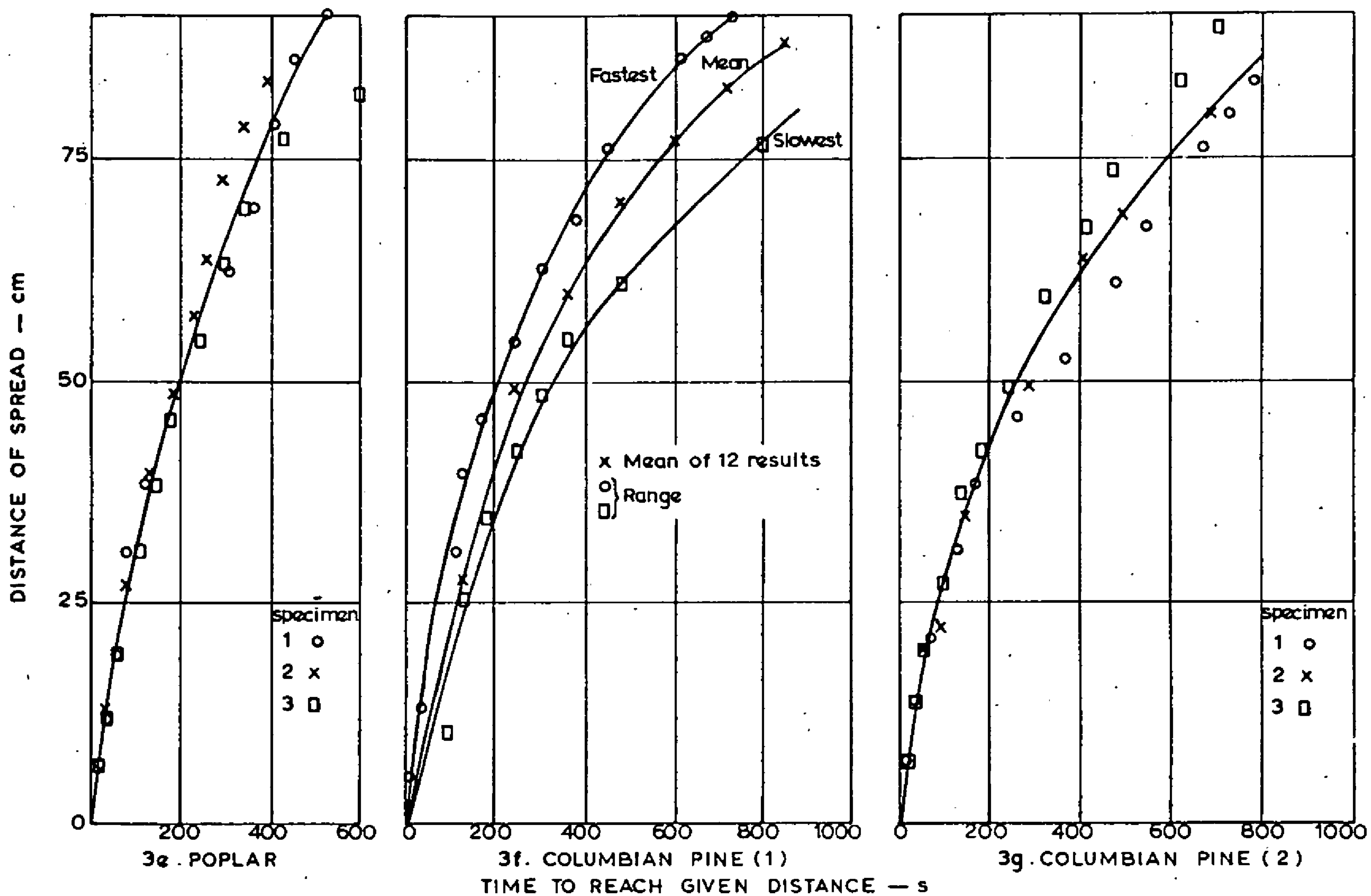



FIG.3e, f & g. SPREAD OF FLAME ON POPLAR & COLUMBIAN PINE 1 & 2.

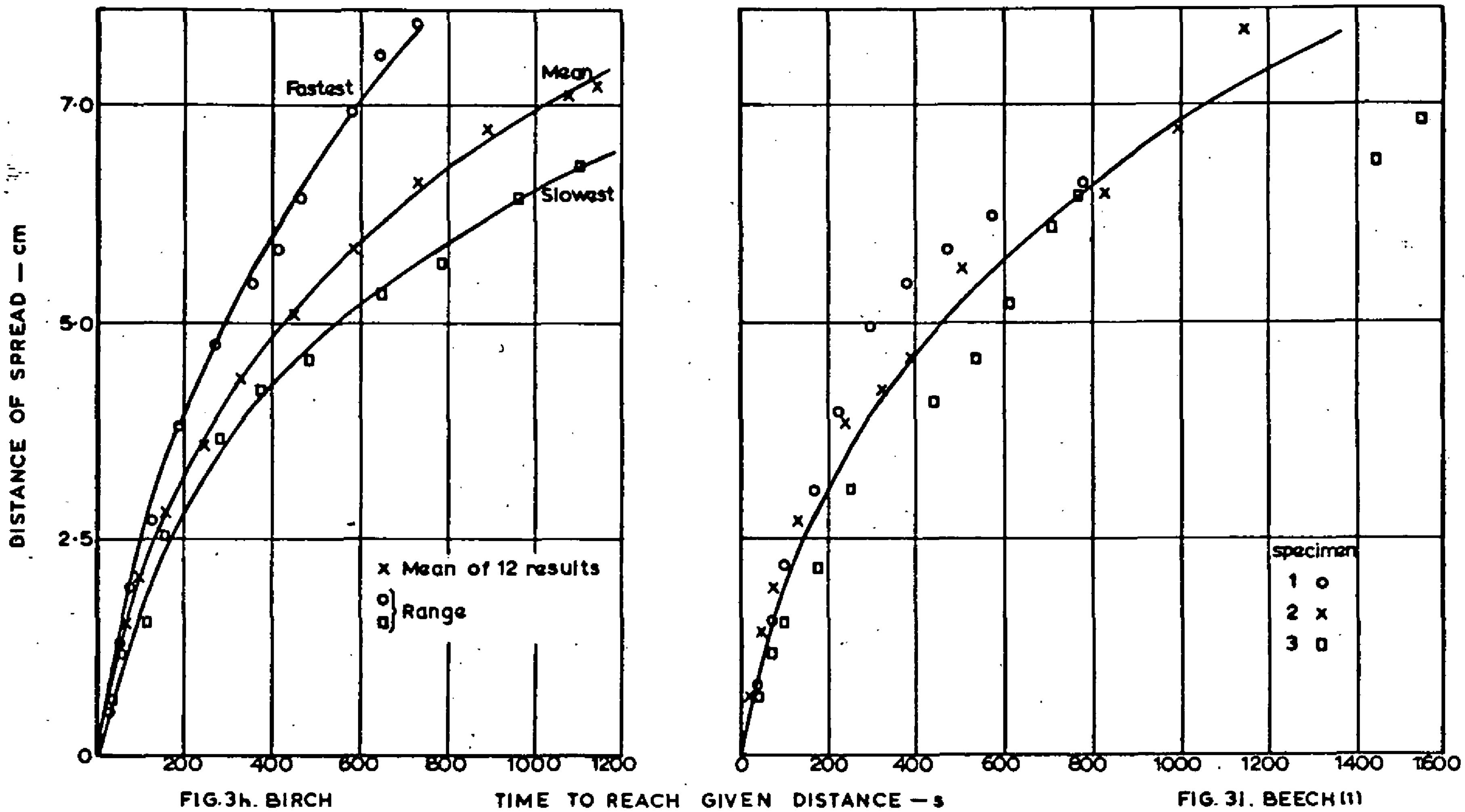



FIG. 3h. & 3i. SPREAD OF FLAME ON BIRCH & BEECH

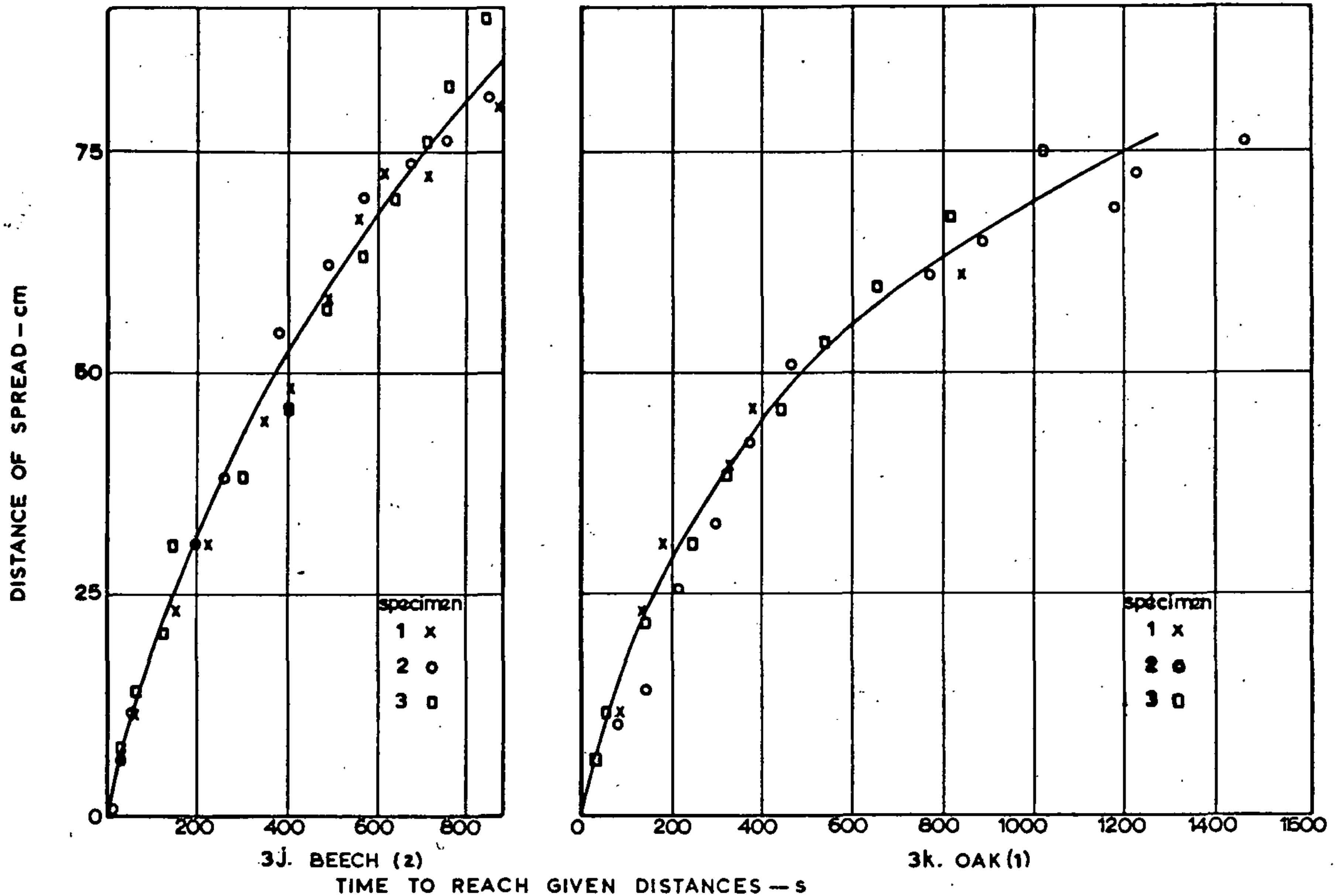



FIG. 3j. & 3k. SPREAD OF FLAME ON BEECH & OAK

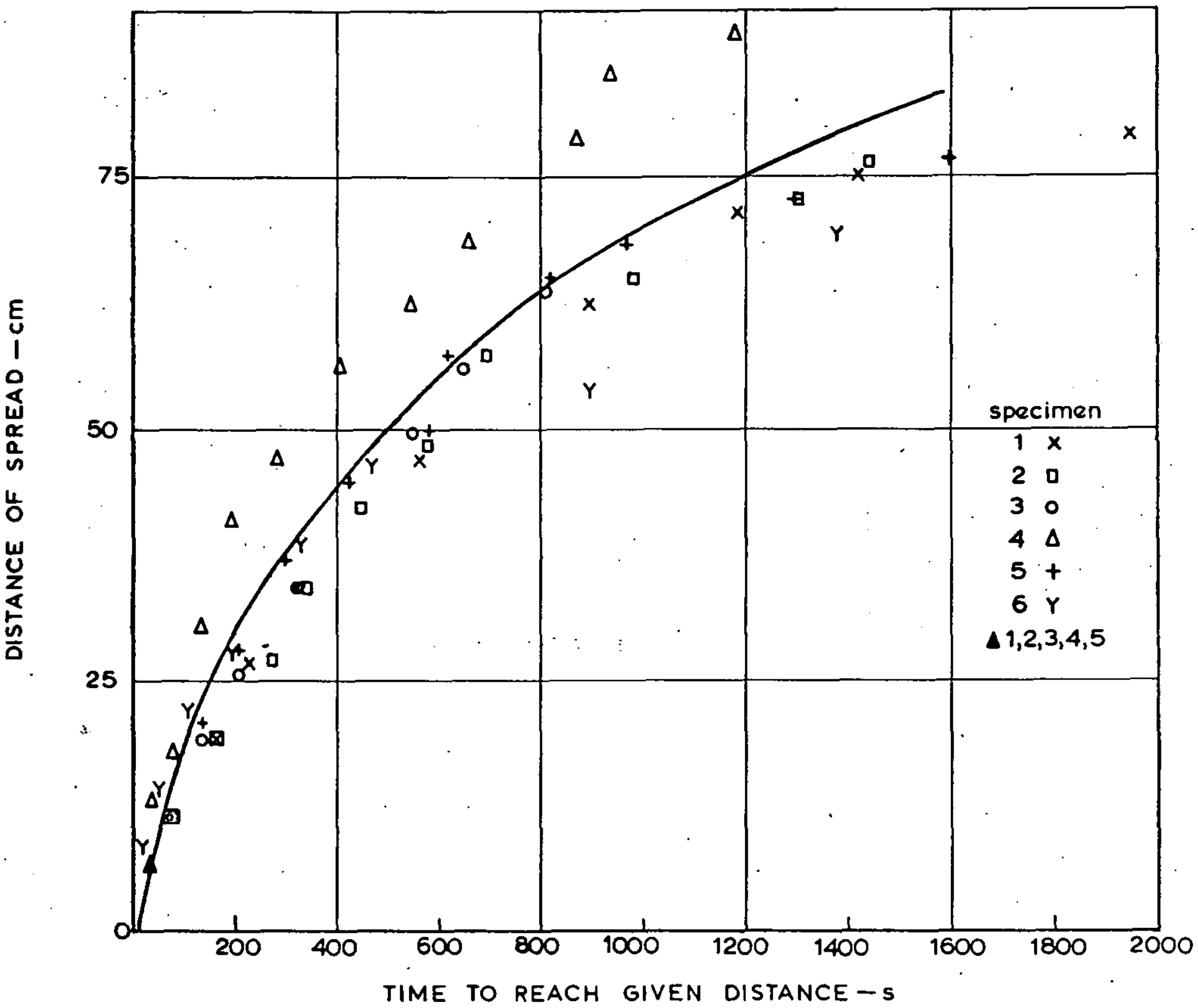



FIG 3L SPREAD OF FLAME ON OAK (2)

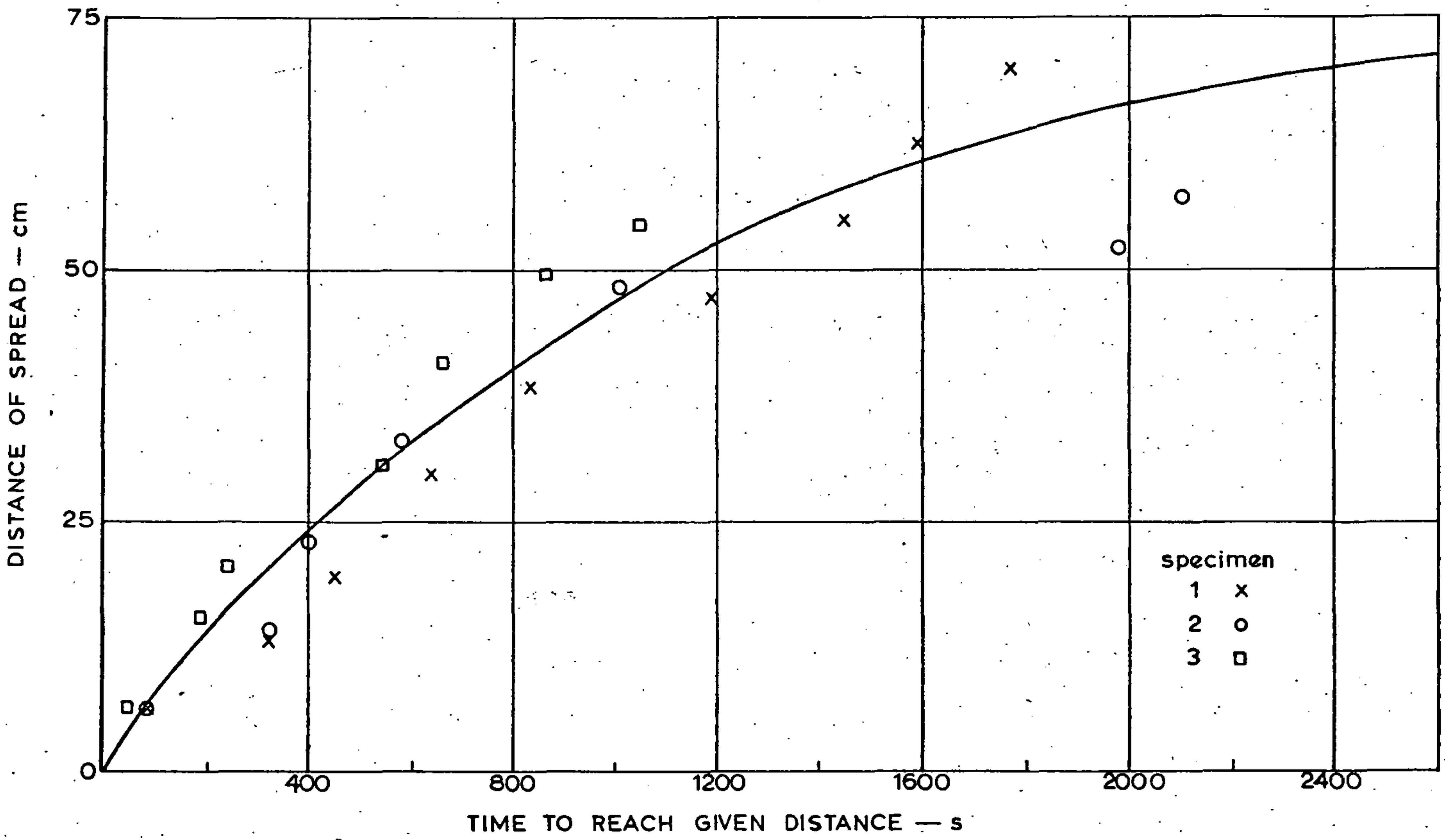



FIG. 3m. SPREAD OF FLAME ON GREENHEART

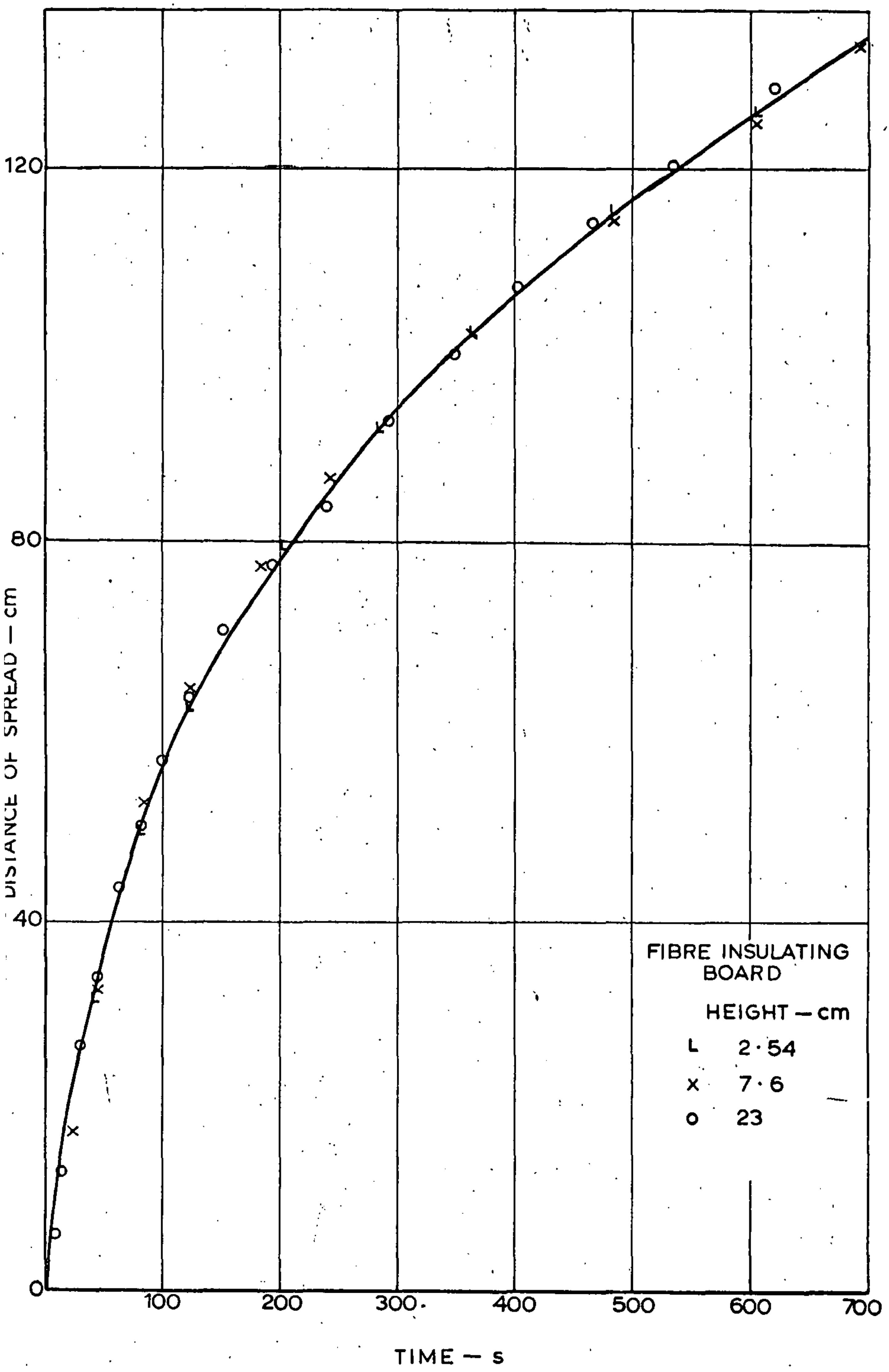



FIG.4. SPREAD OF FLAME — THE EFFECT OF HEIGHT

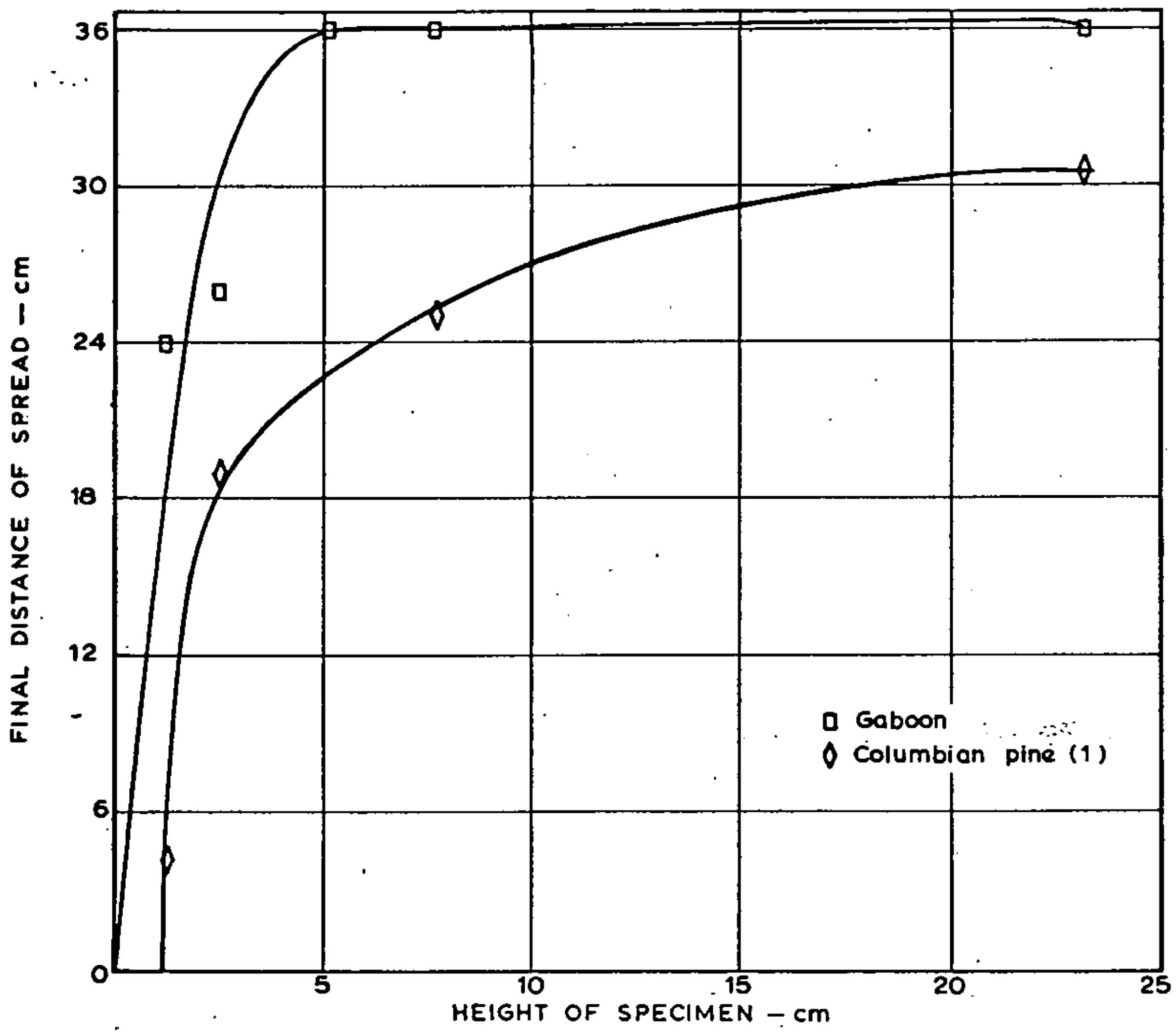



FIG. 5a. EFFECT OF HEIGHT OF SPECIMEN ON FINAL DISTANCE OF SPREAD — STANDARD APPARATUS

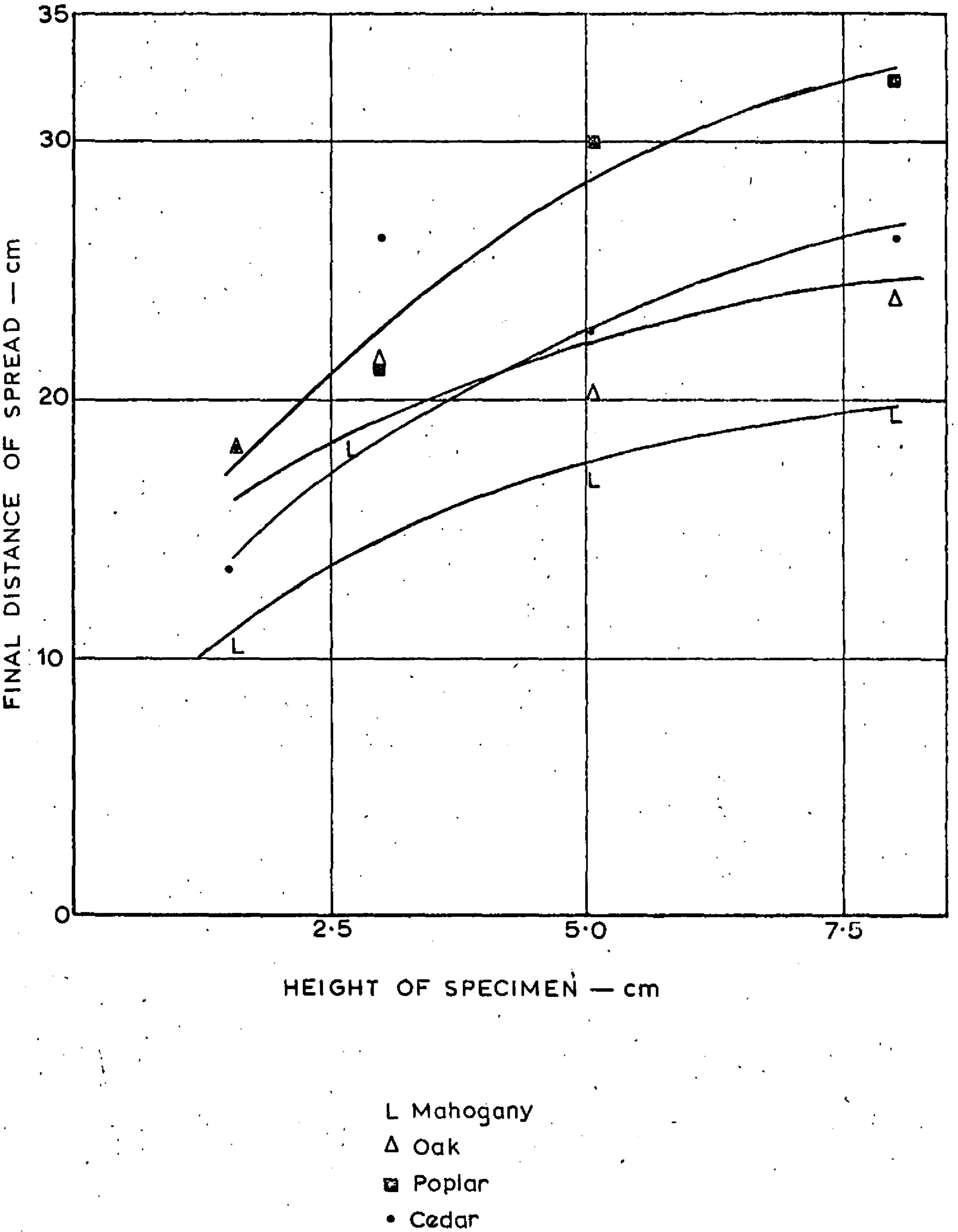



FIG:5b. EFFECT OF HEIGHT ON FINAL DISTANCE OF SPREAD. ( SMALL SCALE APPARATUS )

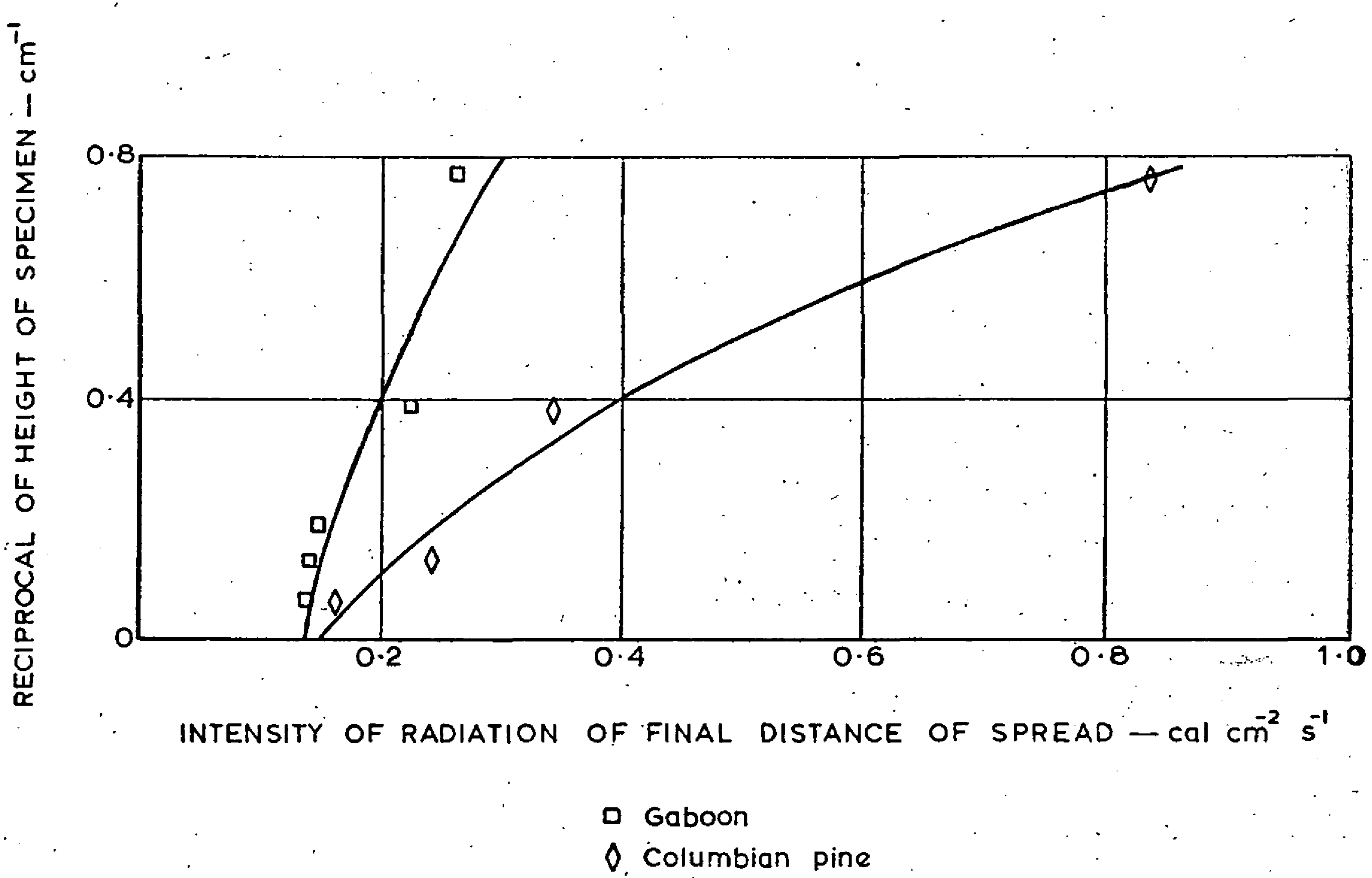



FIG.6a. EFFECT OF HEIGHT ON INTENSITY OF RADIATION NECESSARY FOR FLAME SPREAD

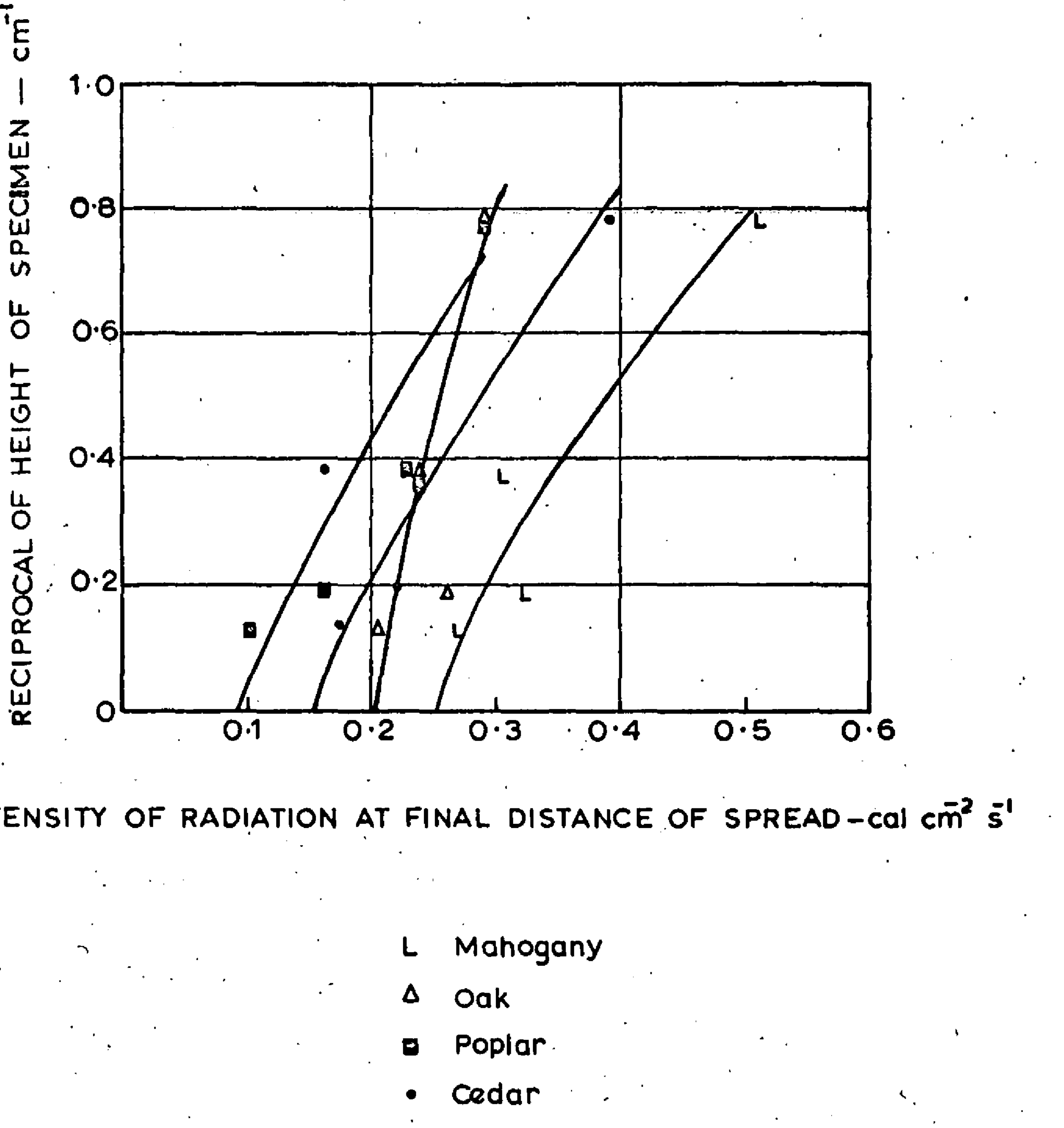



FIG. 6b. EFFECT OF HEIGHT ON INTENSITY OF RADIATION NECESSARY FOR FLAME SPREAD

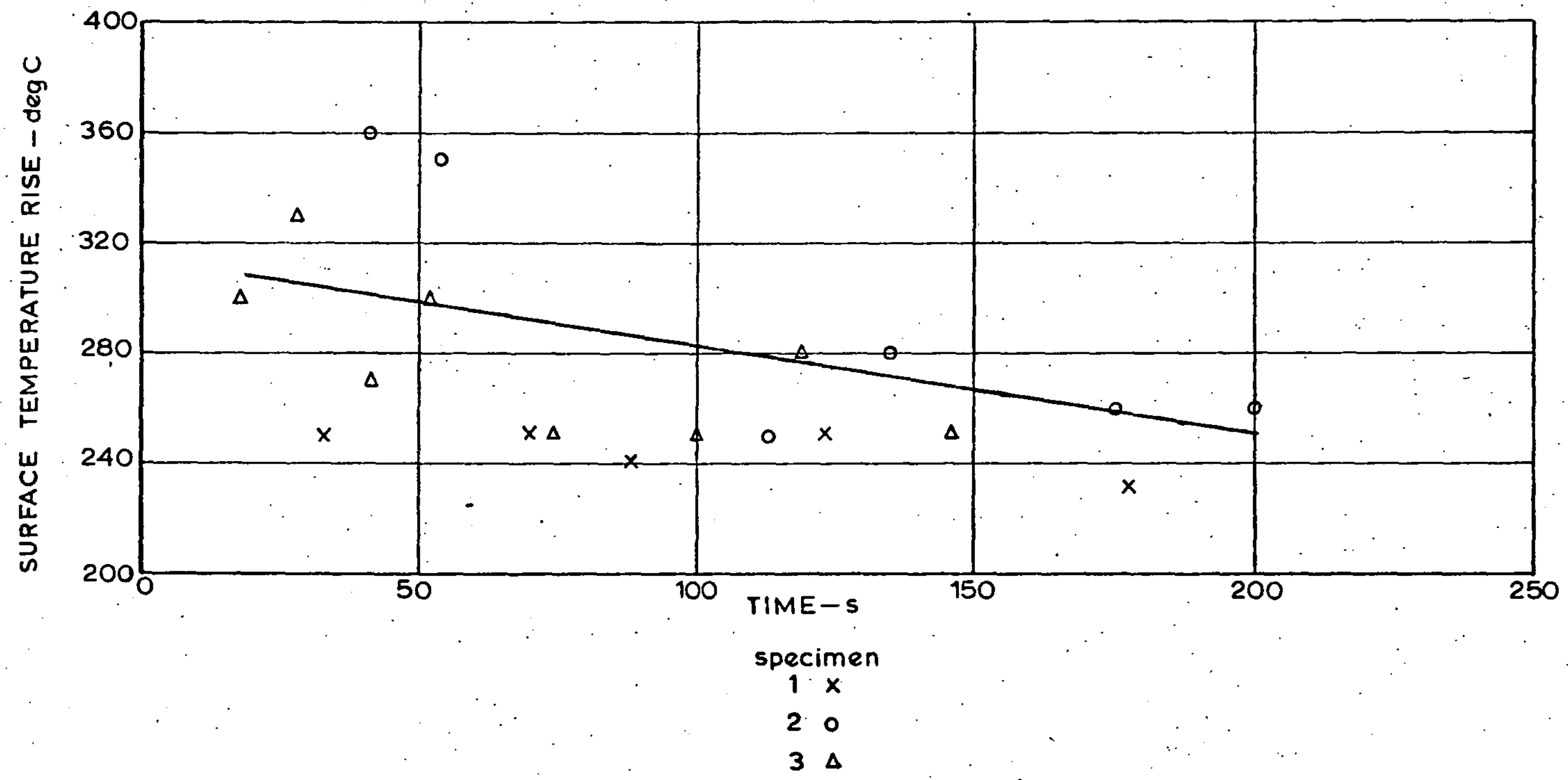



FIG. 7a. SURFACE TEMPERATURE AT IGNITION — EUROPEAN WHITEWOOD

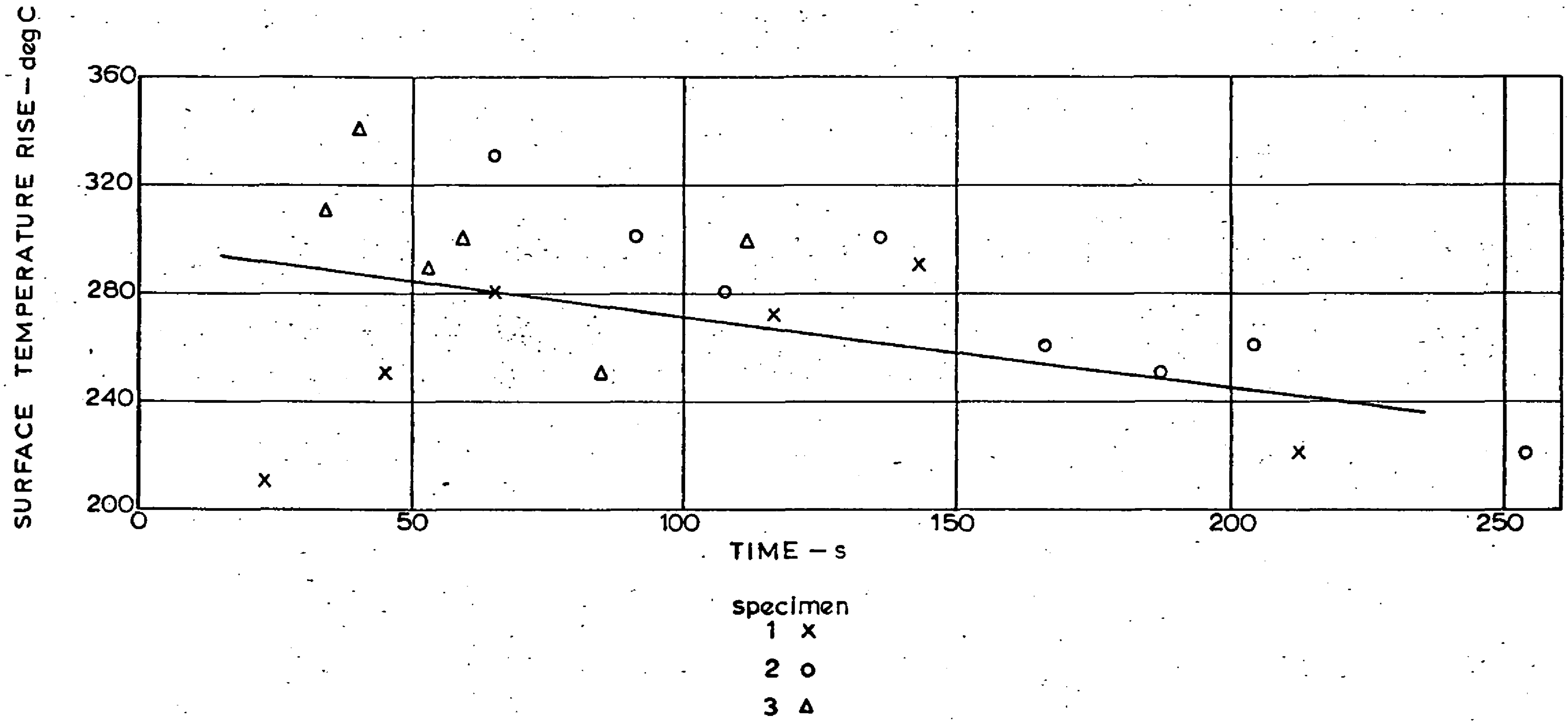



FIG.7b. SURFACE TEMPERATURE AT IGNITION — OAK

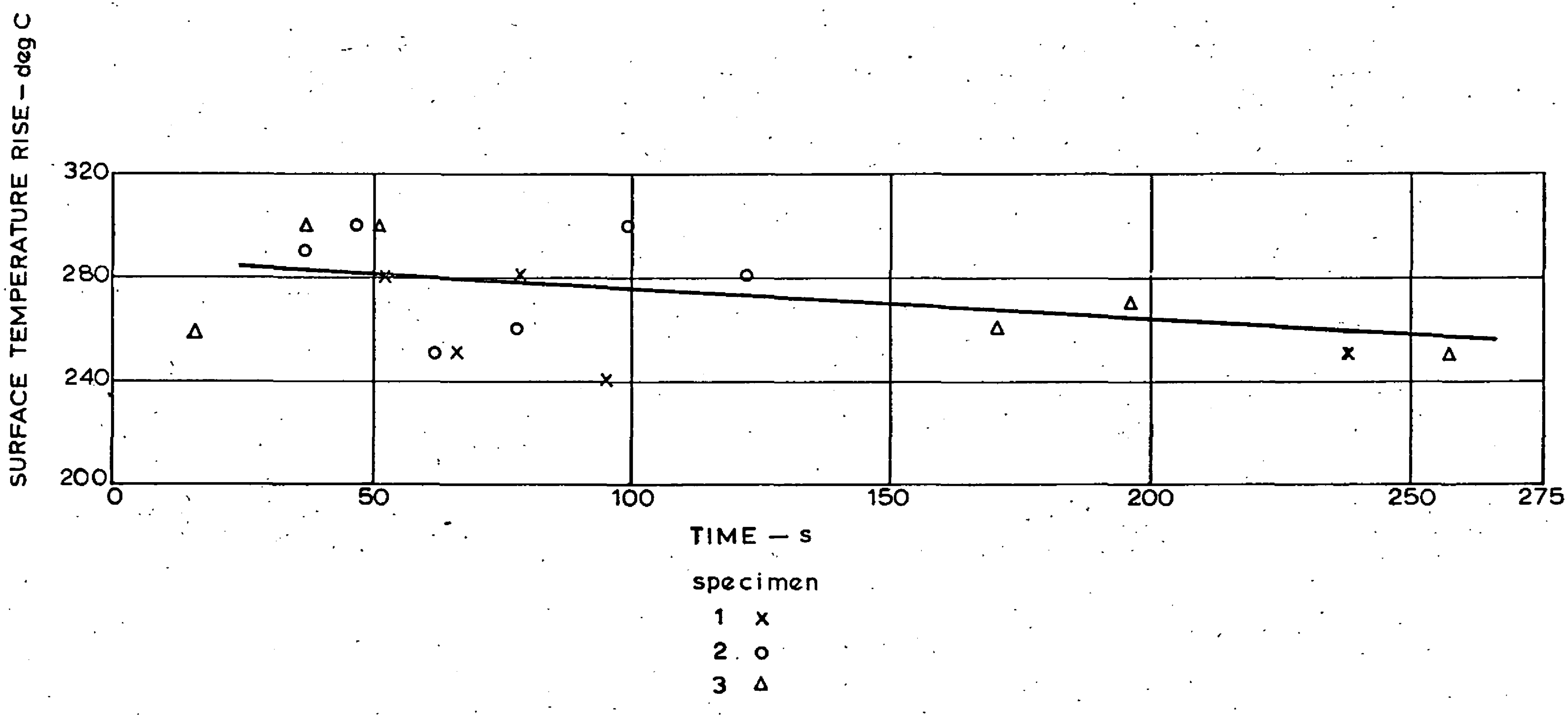



FIG.7c. SURFACE TEMPERATURE AT IGNITION — COLUMBIAN PINE

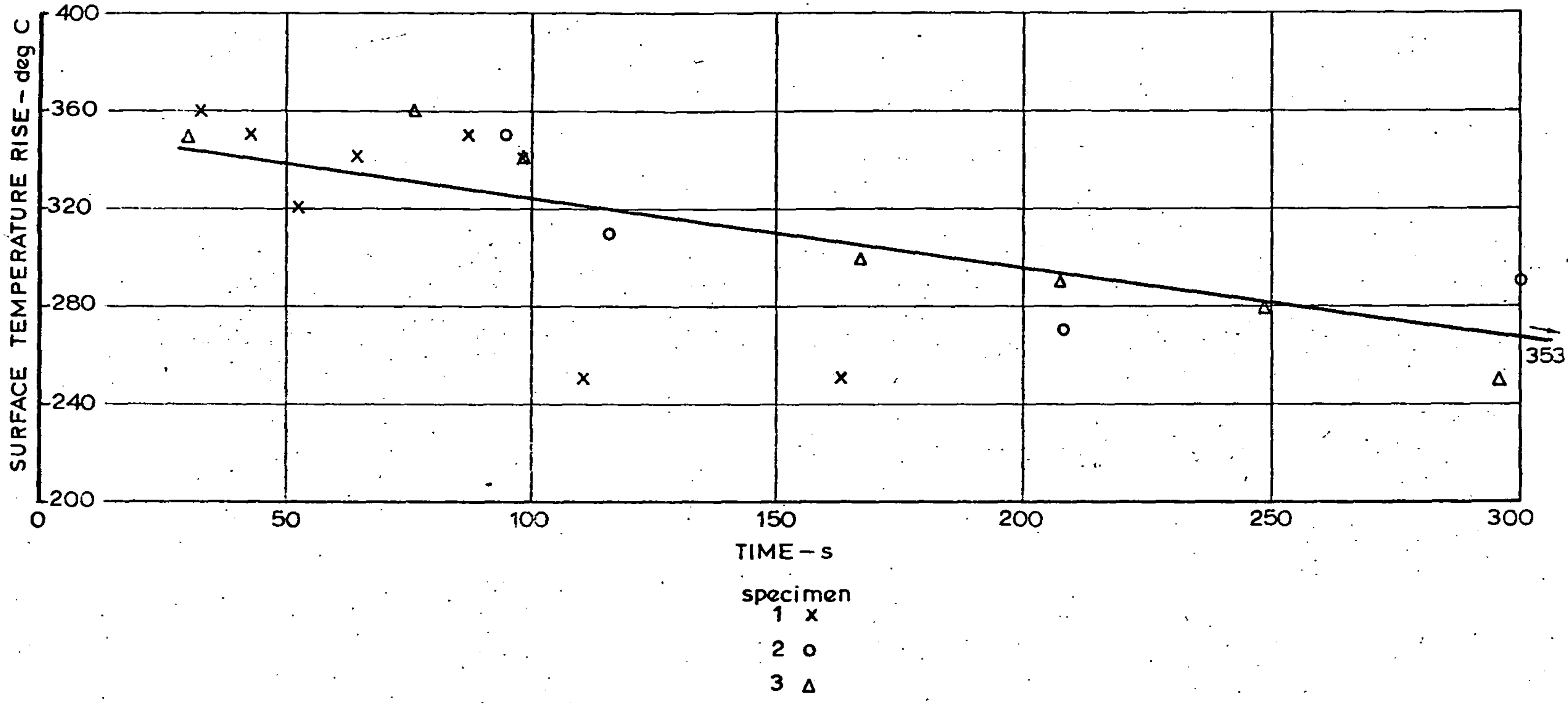
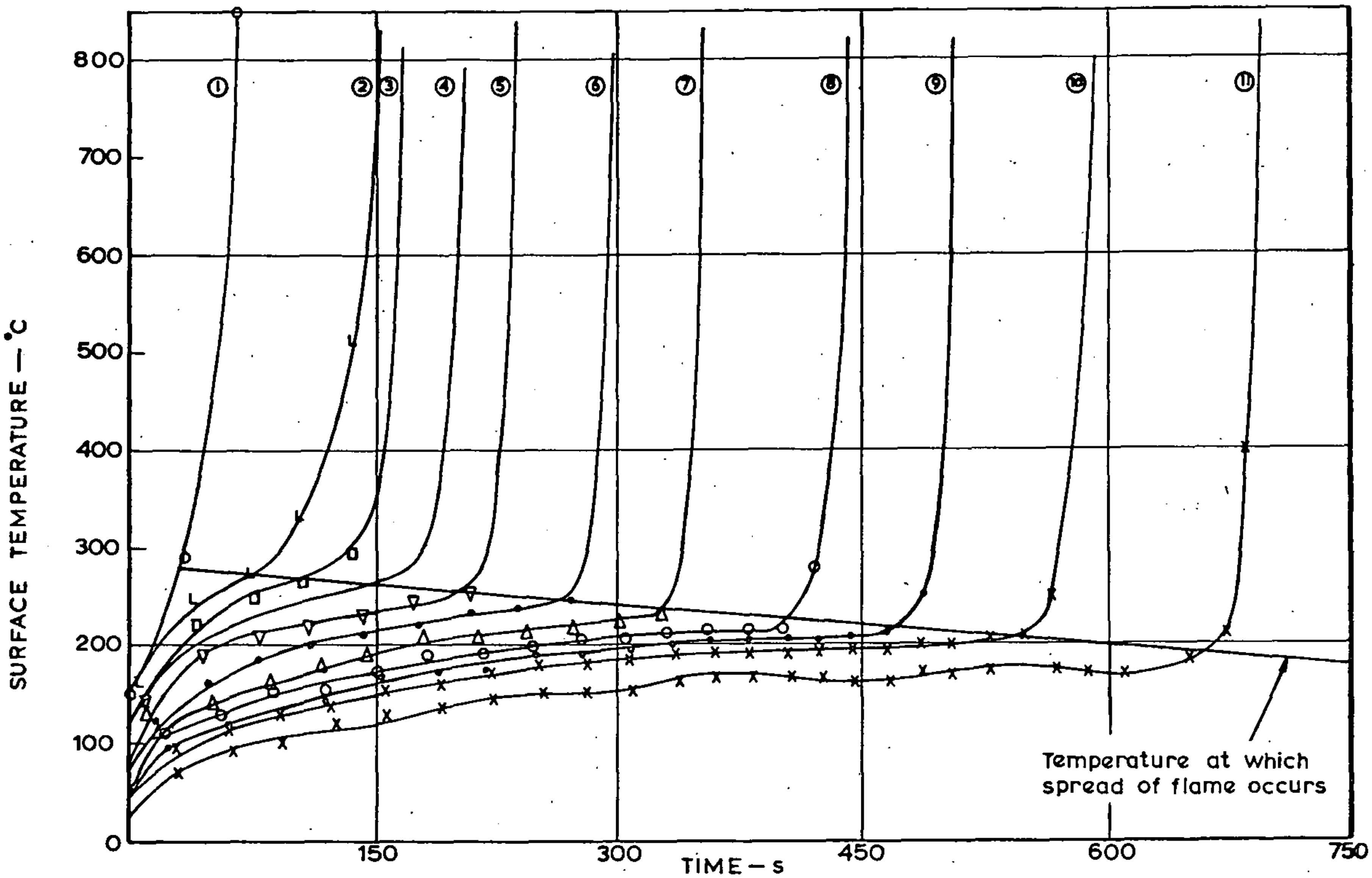



FIG. 7d. SURFACE TEMPERATURE AT IGNITION — HARDBOARD




The figure in the circle represents the distance in inches of thermocouple from hot end

FIG. 8. TEMPERATURE AT SURFACE WHEN REACHED BY FLAME

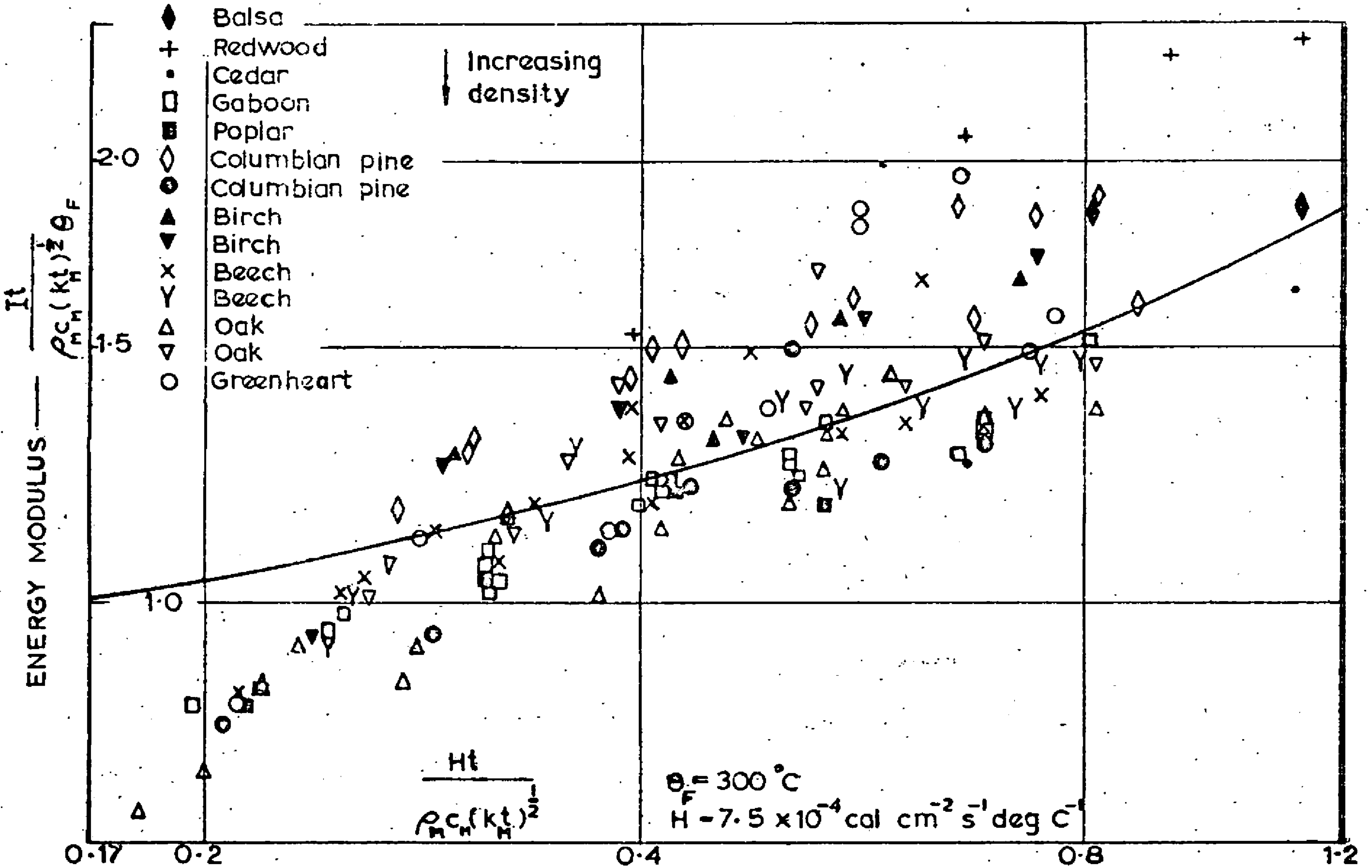



FIG. 9. CORRELATION OF RESULTS ON SPREAD OF FLAME ON THICK MATERIALS

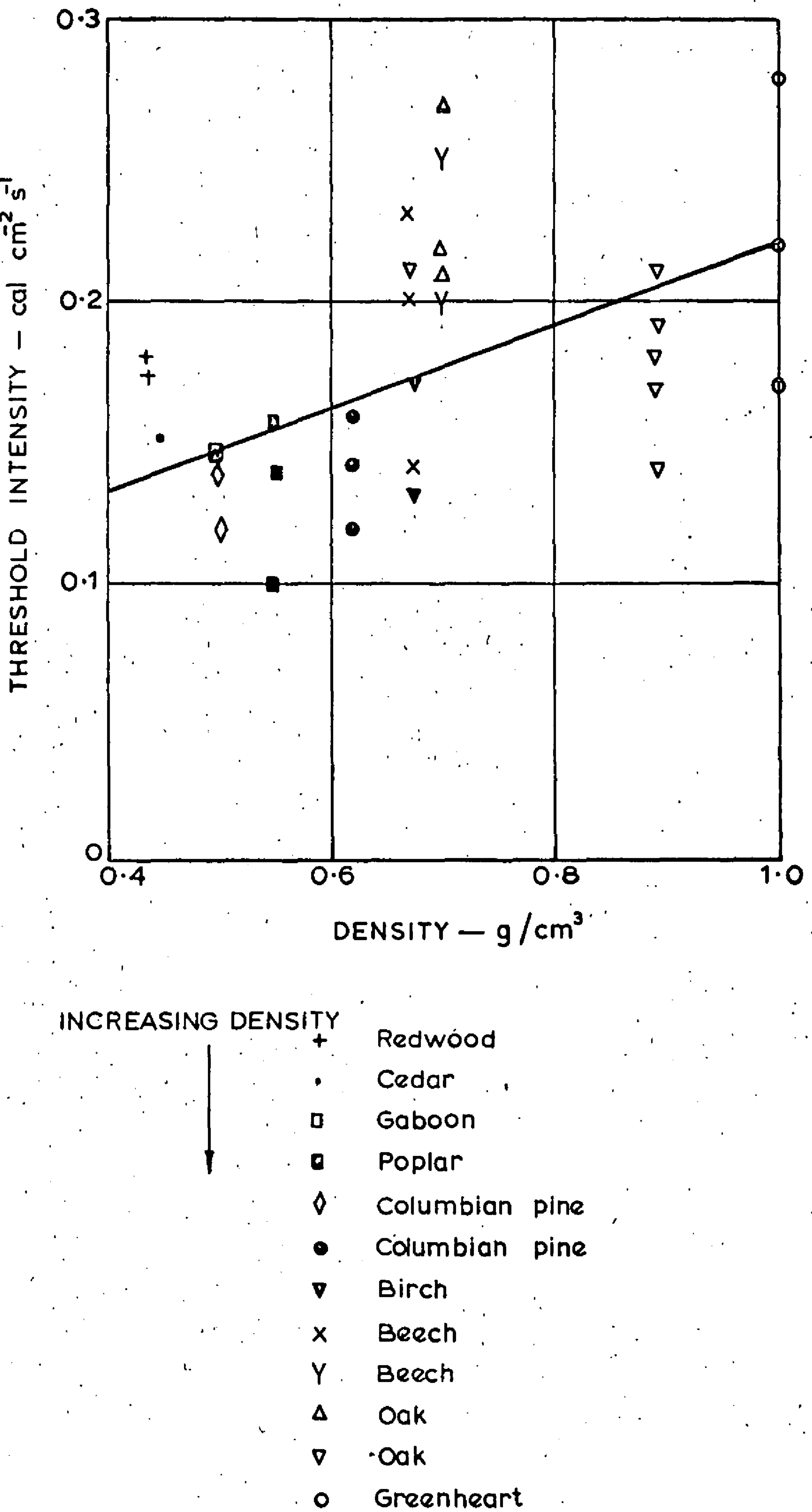



FIG.10. DENSITY AND THRESHOLD LEVEL FOR SPREAD OF FLAME