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EXPERIMENTS ON THE IGNITION OF CELLULOSIC MATERIALS BY RADIATION

by

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SUMMARY

This report describes some measurements of the temperature of the stream of smoky gases emitted from a heated cellulosic solid. The exothermic reactions in this stream can lead to self-ignition and flaming and the report discusses the effects of various factors, e.g. the size of the area heated by radiation, on the likelihood of ignition. It is pointed out that the occurrence of turbulence in the stream of gases is important for ignition to occur.

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Fire Research Station,
Boreham Wood,
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1. Introduction

This note is one of a series on the ignition of cellulosic materials by radiation. Previous reports(1)(2)(3) have been mainly concerned with conditions in the solid itself; conditions in the stream of volatiles issuing from the surface have only been treated incidentally(3)(4). Nevertheless, flaming by its very nature is a process occurring in the gas phase(5)(6) and this report gives the results of several sets of experiments (some summarized earlier(7)(8)) on the flow pattern and temperatures in the volatile stream. The ignition process is then discussed in the light of these results.

The basic experimental method was similar to that adopted earlier(1)(3). A specimen was exposed to a known intensity of radiation either from a gas-fired panel(9), a tungsten filament lamp(10) or a carbon arc(11) and the ignition time was noted.

2. Position of first appearance of flame

At high rates of heating, the flow of the volatile stream appears to become turbulent immediately, i.e. on the surface of the heated specimen, and ignition usually follows very quickly. At lower rates, the flow is clearly laminar near the heated surface and becomes turbulent higher up.

When a cine-camera operating at 120 frames per second was focussed on the stream of volatiles immediately above the top of the irradiated specimen, the photographs showed that flame first appeared in the volatile stream where the laminar flow became turbulent (Plate 1) and then travelled down to the surface. Experiments with a cine-camera operating at 720 frames per second showed that the time taken for the flame to reach the surface from its first appearance was about 0.01 seconds, giving a speed of about 600 cm/s. This is at the high end of a range of velocities of flame propagation in turbulent flow(12).

3. Absorption of radiation in the volatile stream

One possible mechanism for the ignition of the gases could be the absorption of radiation by hydrogen, one of the principal constituents of the volatiles at high rates of heating(13). Twin tungsten filament lamp sources were arranged so that radiation from one passed through the volatile stream produced by the other irradiating the surface of the specimen (Fig.1); there was no alteration in ignition time when the second lamp was switched on during the experiment and so absorption of radiation does not appear to initiate the reaction, at least in the range of these experiments.

4. Temperature measurements in the volatile stream

The temperatures of the surface and of the volatile stream were then investigated both when ignition did occur and when it did not; the intensity level was the same in each case and was near the threshold for ignition; the presence of an external draught(4) being necessary to initiate ignition.

Temperatures in the volatile stream were measured by means of thermocouples placed above the specimen, temperatures on the surface by thermocouples placed in a thin slit. The thermocouples used[*] in these experiments were made from (45 S.W.G.) chromel-alumel wire and had a time constant of about 0.2 s for 95 per cent of full reading. The output was recorded automatically.

A typical experiment consisted of exposing a specimen to radiation, recording the temperature-time curve at <u>one</u> position in the volatile stream, and measuring the ignition time if it occurred. Fig.2a shows the mean result for two exposures resulting in ignition and Fig.2b the mean of two where ignition did not occur. Similar results were obtained with the thermocouple in different positions in the same vertical plane.

The temperature <u>distribution</u> in the volatile stream just before and just after ignition is shown in Figs.3a and 3b. Where ignition did not occur, the temperature distribution in the volatile stream is given for the time just after the surface temperature reached 500°C at which temperature ignition might be expected(3) (Fig.3c); the corresponding rises in temperature just [illegible] below the surface are given in Fig.4. Each experiment was repeated several times to obtain a mean profile. At a rate of heating near to the threshold for ignition (Figs.2a and 2b), the temperatures of the volatiles as they emerge from the solid do not appear to differ whether or not ignition is about to occur. The same is true for the surface temperature (Fig.4)[**].

There is a peak in the temperature curve in Fig.3b at a point some distance from the surface but in view of the thermal inertia of the thermocouples compared with the short time for the flame to strike back to the surface it is not practical to attempt to interpret this. If the reaction leading to ignition is initiated by the volatiles mixing with the air, turbulent mixing would increase the gross heat output both by extending the region where the reaction takes place and by increasing the rate at which the reaction occurs.

Experiments reported earlier(4) showed that introducing a draught could sometimes produce ignition when otherwise it did not occur. This effect is consistant with regarding the draught as introducing turbulence where otherwise it did not occur at all or where it developed too far from the heated surface for the gases to be hot enough to ignite.

The present results also help to explain why large irradiated areas of the same cellulosic material are more quickly ignited than small ones at the same intensity of irradiation(16). For a heated plume of inert gas, the smaller the total amount of gas in the plume, the farther away from the source is the onset of turbulence. The same effect would be expected for reacting gases up to the point at which heating as a result of the reaction becomes significant. This

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[*] In order to test whether the thermocouples in the volatile stream would affect the ignition process, specimens of fibre insulation board were exposed to an intensity of radiation of about 3 cal cm^{-2} s^{-1} (Fig.1); a number of wires and fibres of different thicknesses were placed in the volatile stream and the ignition times with each wire and fibre were recorded. No significant variations in ignition time were found. The presence of a cotton fibre shortened the ignition time and the thicker metal wires ($>$ 26 S.W.G.) often prevented ignition altogether, but the presence of the other fibres had no effect.

[**] If chemical heating in the solid were significant, there should be a point of inflection in the temperature-time curve (Fig.4) above a certain temperature (c.250°C). No such inflection was found; it is also absent from the surface heating curves given elsewhere(14)(15).

means that the smaller areas require a longer heating time to raise the temperature of the volatiles to a given value at the greater distance where turbulence commences so that the ignition time is longer.

5. The effect of the cold areas surrounding the irradiated area

The area heated by the radiation is necessarily small when sources of high intensity are used(10, 11) so that the specimen holder may receive little of the incident radiation. Unless care is taken in mounting the specimen in such a way that the specimen is clear of its holder, this may interfere in the ignition process. In particular, the minimum intensity at which ignition occurs is found to be higher and the ignition time longer if the holder is unheated than if it is heated. The effect is analagous to that discussed above in connection with the size of the irradiated area.

A hot surround effectively increases the amount of hot gas rising in the plume by adding heated air to the stream of volatiles and turbulence would occur more readily than with a cold surround so that the threshold for ignition would be lower. Also with a hot surround the higher temperature of the surrounding air with which the gases mix would tend to make ignition easier.

6. Conclusions

Ignition, that is, the first appearance of flame, occurs where the steam of volatiles becomes turbulent. If turbulence does not occur within a short distance of the point of emission of the volatiles, ignition does not occur even though the temperatures of the surface of the solid and in the volatile stream are the same as when ignition does occur. This may be due to turbulence increasing the rate of gross heat output in the volatile air stream by increasing the size of the reacting zone.

7. Acknowledgments

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8. References

1. LAWSON, D. I. and SIMMS, D. L. The ignition of wood by radiation. Brit.J. App.Phys. 3 288-92, 1952 and 3, 394-6, 1952.

2. THOMAS, P. H. and SIMMS, D. L. Thermal damage by radiation and chemical decomposition. Joint Fire Research Organization Fire Research Note No.331/1958.

3. SIMMS, D. L. The ignition of cellulosic materials by radiation. Combustion and Flame (to be published).

4. SIMMS, D. L. The influence of external air movements on the ignition of materials by radiation. Joint Fire Research Organization F.R. Note No.305/1957.

5. LAWRENCE, E. K. Analytical study of flame initiation. S.M. Thesis, Chemical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1952.

6. MARTIN, S. B. The mechanisms of ignition of cellulosic materials by intense thermal radiation. Report No.TR 102 United States Naval Radiological Defence Laboratory, San Francisco 24, California, U.S.A. February 1956.

7. Fire Research 1954. Her Majesty's Stationery Office, London, 1955.

8. Fire Research 1955. Her Majesty's Stationery Office, London, 1956.

9. SIMMS, D. L. and MILLER, Joan E. Radiation characteristics of a gas-fired radiant panel. Joint Fire Research Organization F.R. Note No.217/1955.

10. SIMMS, D. L., PICKARD, R. W. and LAW, Margaret. A source of radiation employing a tungsten filament lamp and an ellipsoidal mirror. Joint Fire Research Organization F.R. Note No.355/1958.

11. HINKLEY, P. L. Source of high intensity radiation employing an arc lamp and an ellipsoidal mirror. Joint Fire Research Organization F.R. Note No.270/

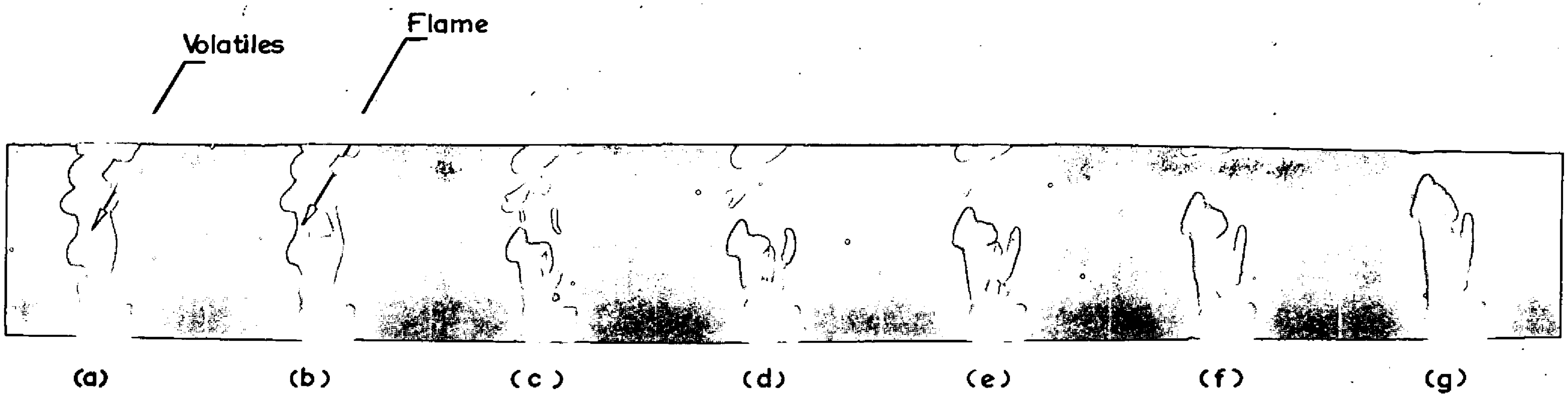
12. PALMER, K. N. A fundamental study of flame arresters. 1. Wire gauze arresters in a narrow tube. Joint Fire Research Organization F.R. Note No.309/1957.

13. PLUM, W. Ignition of combustible materials. U.S. Naval Radiological Defence Laboratory, San Francisco, 24, California, U.S.A. (Private Communication).

14. WILLIAMS, C. C. Damage initiation in organic materials exposed to high-intensity thermal radiation. Technical Report No.2. Fuel Research Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1953.

15. GARDON, R. Temperatures attained in wood exposed to high intensity thermal radiation. Technical Report No.3. Fuel Research Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1953.

16. SIMMS, D. L., LAW, Margaret, HINKLEY, P. L. and PICKARD, R. W. The effect of size of irradiated area on the spontaneous ignition of materials. Joint Fire Research Organization F.R. Note No.307/1957.



Pictures taken at about $\frac{1}{100}$ s exposure
Note ignition occurs above the specimen
outside the radiation field.

SUCCESSIVE STAGES IN THE IGNITION OF WOOD BY RADIATION

PLATE 1.

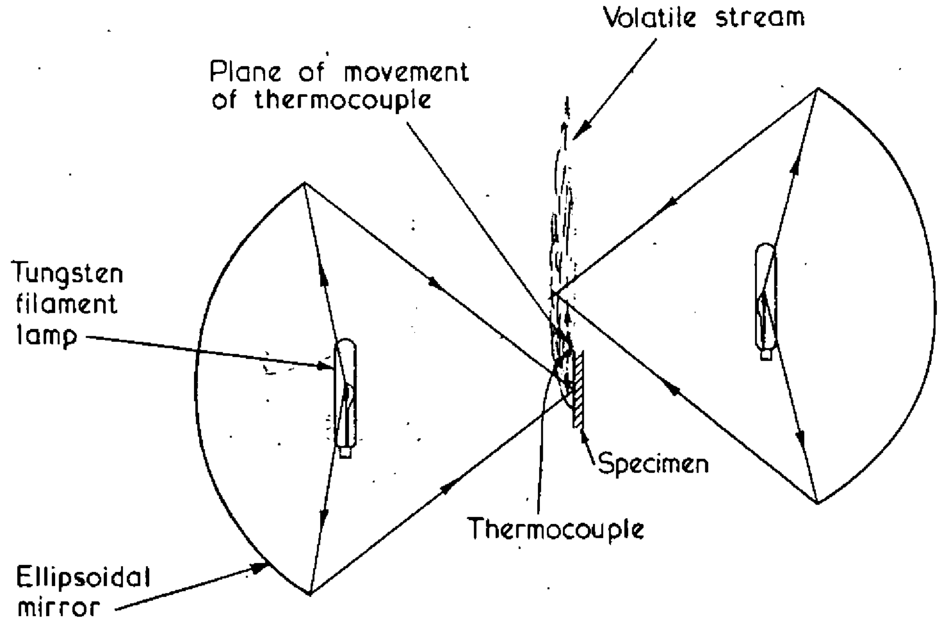
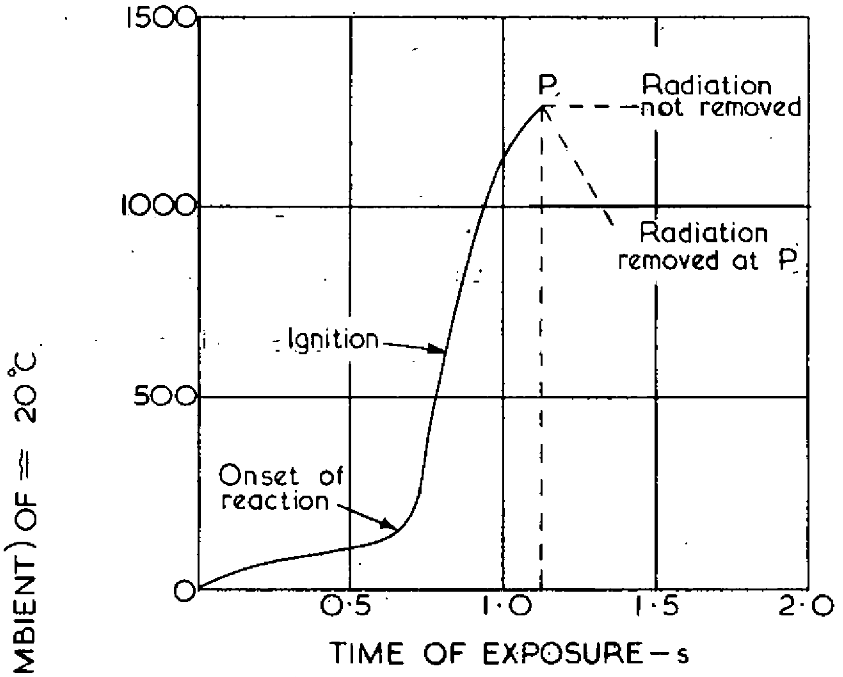
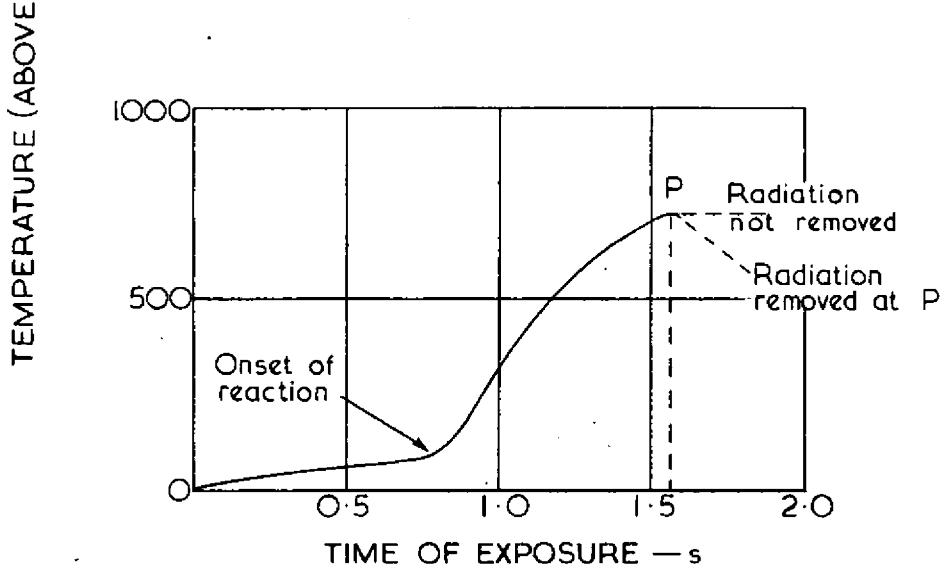


FIG.1. DIAGRAM OF APPARATUS



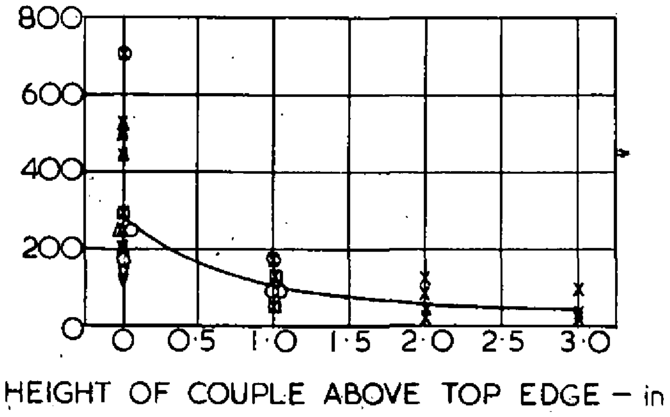
(a) IGNITION OCCURRED



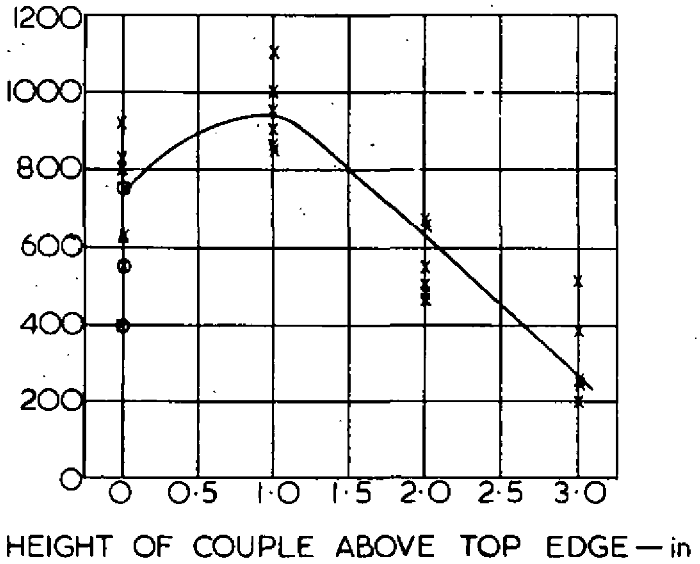
Radiation intensity — 4·5 cal cm^{-2} s^{-1}
Thermocouple level with top of specimen

(b) IGNITION DID NOT OCCUR

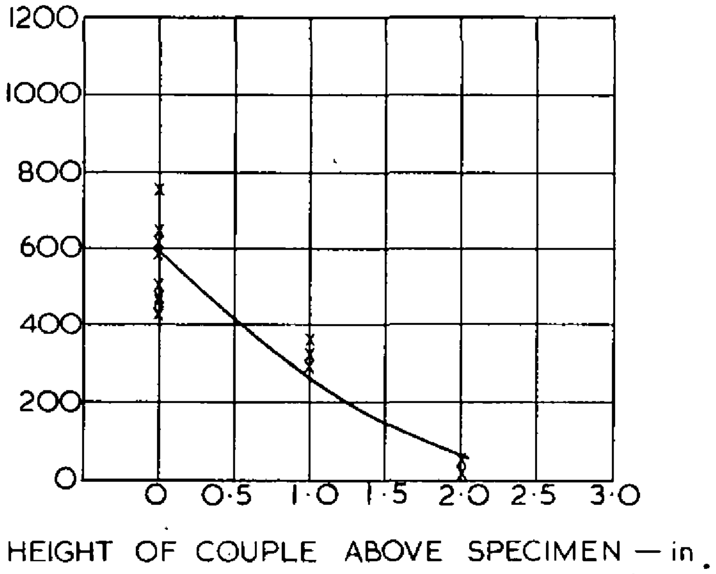
FIG.2 TEMPERATURES IN VOLATILE STREAM



(a) JUST BEFORE IGNITION



(b) JUST AFTER IGNITION (0·25s)



(c) TEMPERATURE PROFILE IN VOLATILE STREAM 0·25s AFTER SURFACE OF SPECIMEN REACHES 500 °C (NO IGNITION)

FIG. 3. STREAM TEMPERATURE PROFILE

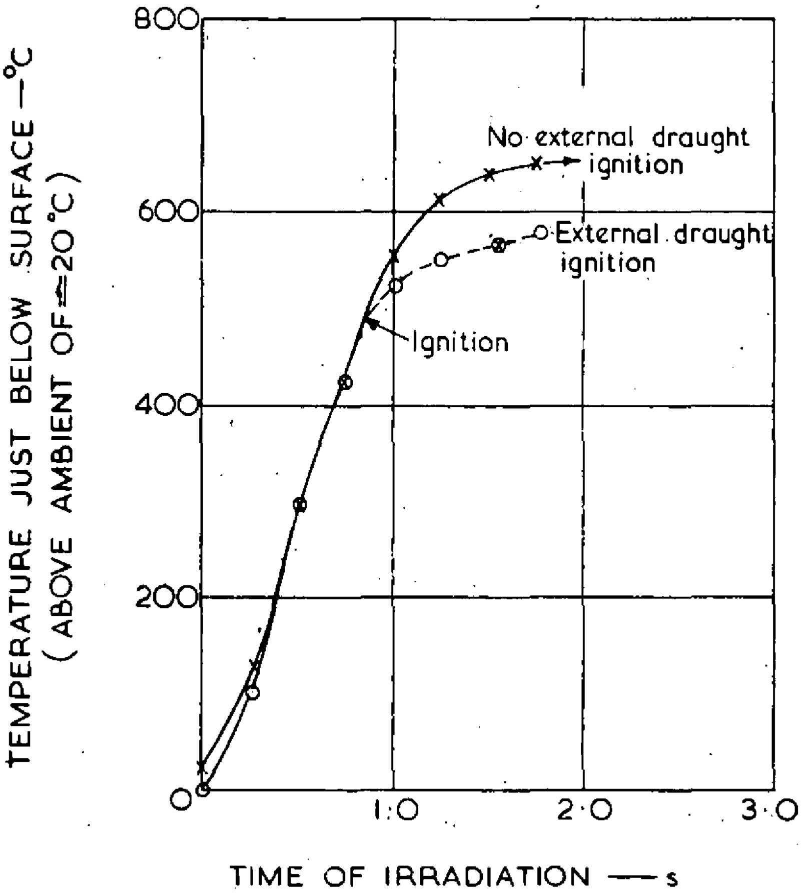


FIG. 4. TEMPERATURE JUST BELOW SURFACE (INTENSITY OF RADIATION – 4·5 cal $cm^{-2} s^{-1}$)