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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
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THE EFFECT OF ABSORPTIVITY ON THE IGNITION OF MATERIALS BY RADIATION

by

D. L. Simms, Margaret Law and P. L. Hinkley

Summary

The effect of the absorptivity of the surface of a material on its ignition by radiation has been investigated. An effective absorption factor has been found for different woods, cotton and paper.

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1. Introduction

In order to correlate the ignition time of materials with the intensity of radiation and with their physical properties, the absorptivity of the surface must be known (1). Normally the absorptivity is considered as a constant for any material and a given radiation source, but in problems of ignition the colour of the irradiated surface may change during the course of exposure and an empirical absorption factor which is independent of exposure time cannot be found. This paper describes experiments carried out to measure the absorptivity of irradiated materials and shows how the effects of various intensity levels may be taken into account.

Experiments were carried out using three sources of radiation of different colour temperatures on the materials listed in Table 1. To increase the absorptivity of the woods to unity some specimens were coated with carbon black. The filter, blotting papers and cotton were obtained dyed.

Table 1

Materials tested

Type of ignition	Material	Wt/unit area g/cm^2	Density (oven dry) g/cm^3	Colour	Source of radiation
Spontaneous	Fibre insulation board	0·30	0·24	Natural and candle black	Panel Carbon arc
	Oak (quercus sp.)	0·42	0·66	Natural and candle black	Carbon arc Tungsten lamp
	Mahogany (khaya ivorensis)	0·33	0·52	Natural and candle black	Carbon arc
	Western red cedar (thuja plicata)	0·23	0·37	Natural and candle black	Carbon arc
	Filter paper	0·01	0·53	White and black	Carbon arc
	Cotton	0·023	0·66	White	Panel Carbon arc Tungsten lamp
		0·026	0·55	Black	
	Blotting paper	0·031	0·43	White, green and yellow	Carbon arc
Pilot	Fibre insulation board	0·30	0·24	Natural and candle black	Tungsten lamp

2. Experiments and results

Oven-dry specimens were exposed to radiation and the time to ignite was noted, each value being the mean of six readings. A few experiments on pilot ignition (2) were made with a spark $\frac{1}{4}$ in. above and $\frac{1}{8}$ in. away from the exposed area of the surface of the specimen.

The three sources of radiation and the methods of exposing the specimens have been described in detail elsewhere (3), (4), (5).

2.1. Radiant panel source (3)

The radiant panel, 1,100°K, which burns a gas/air mixture is 1 ft square and gives uniform radiation over an area 60 cm^2.

The intensity of radiation was varied by altering the distance of the specimen from the panel.

2.2. Tungsten filament lamp source (4)

The filament of the 1,000 watt lamp is at the first focus of a front silvered ellipsoidal mirror and radiation is reflected by the mirror to the specimen placed at the second focus. The specimen receives uniform radiation over an area 1 cm^2. The intensity of radiation may be varied by adjusting the power input. For the range of intensities over which ignition occurs the colour temperature of the filament ranges from 2,400°K to 3,000°K, and assuming that the colour temperature is proportional to the black body temperature, the wavelength for peak intensity ranges from 1.2 μ to 1 μ. This change in colour temperature makes little change in absorption factor.

2.3. Carbon arc source (5)

The carbon arc is also at the first focus of an ellipsoidal mirror and the specimen at the second focus receives substantially uniform radiation over an area 3 cm^2. The intensity of radiation may be varied by a venetian blind shutter.

2.4. Results

The ignition times for the different materials for different radiant intensities are given in Figs. 1A to 3A, Appendix. For any ignition time the intensity to produce ignition is less for the blackened than the unblackened material. The minimum intensity for ignition is the same or slightly higher for unblackened specimens.

3. Discussion of results

The ratio of the intensity to ignite a blackened material (I_B) to the intensity to ignite the unblackened material (I_{UB}) is given in Figs. 1, 3, 4 for different ignition times. This ratio is the effective absorption factor for the unblackened material and increases with ignition time reaching a steady value for the longer times. It is thought that the rise in the ratio with exposure time is a reflection of the relatively longer period of irradiation in the charred i.e. black condition at low intensities of irradiation. If the surface of a specimen reaches the charring temperature after exposure time T_1 and the ignition temperature after a further time T_2 then the ratio $\frac{T_2}{T_1}$ will be larger for low rates of heating primarily as a result of surface cooling. As $\frac{T_2}{T_1}$ increases the mean absorptivity increases.

The intensity to ignite white and yellow blotting paper is compared with the intensity to ignite green blotting paper in Fig. 2. In the absence of black blotting paper the absorptivities are only given relative to green blotting paper. The ratio $\frac{I_B}{I_{UB}}$ for cotton and filter paper does not vary so markedly with ignition time as the ratio for the woods. The effective absorption factors obtained from the constant parts of the curves are given in Table 2.

Table 2

Effective absorption factors for different materials

Material	Source of radiation	Time to ignite s	Absorption factor
Natural mahogany	Carbon arc lamp	Over 10	0·95
" cedar		Over 7	0·85
" oak		Over 10	0·7
White cotton		Over 3	0·3
Natural fibreboard	Panel	Over 15	1·0
White cotton		Over 15	1·0
Natural oak	Tungsten lamp	Over 15	0·6

The variation of absorptivity with wavelength has been measured directly over the wavelength range 0·4 μ to 3·4 μ for natural fibre insulation board, mahogany and oak at the National Physical Laboratory. The absorption factors for the three sources of radiation have been calculated for this wavelength range and are given in Table 3.

Table 3

Absorption factors for natural woods

Material	Absorption factor		
	1,100°K black body	3,000°K black body	Carbon arc source
Fibre insulation board	0·61	0·33	0·35
Oak	0·71	0·45	0·48
Mahogany	0·64	0·41	0·46

One would expect that as the ignition time approached zero the ratio $I_B/_{I_{UB}}$ would tend to a value equal or slightly greater than the calculated values given in Table 3, the extent of the excess being dependent on the relative magnitudes of the heating necessary to produce charring and to produce ignition. Unfortunately it has not been possible to obtain values of $\frac{I_B}{I_{UB}}$ for very short ignition times, but it does appear possible to extrapolate the curves to values at zero ignition time which are in reasonable agreement with those in Table 3 except that for fibreboard with the panel source (curve 1, Fig. 3) the limiting value exceeds the calculated value by about 0·2.

It has been observed that the minimum intensity for some of the unblackened or white specimens is slightly higher than for blackened specimens of the same kind and it may be that in the process of charring the volatiles become exhausted.

4. Conclusions

The experiments show that the effective absorption varies with the exposure time by as much as 60 per cent. As the ignition time increases the effective absorption factor reaches a constant value and estimates of this have been obtained for oven dry fibre insulation board, oak, mahogany, cedar, white filter paper and white cotton.

References

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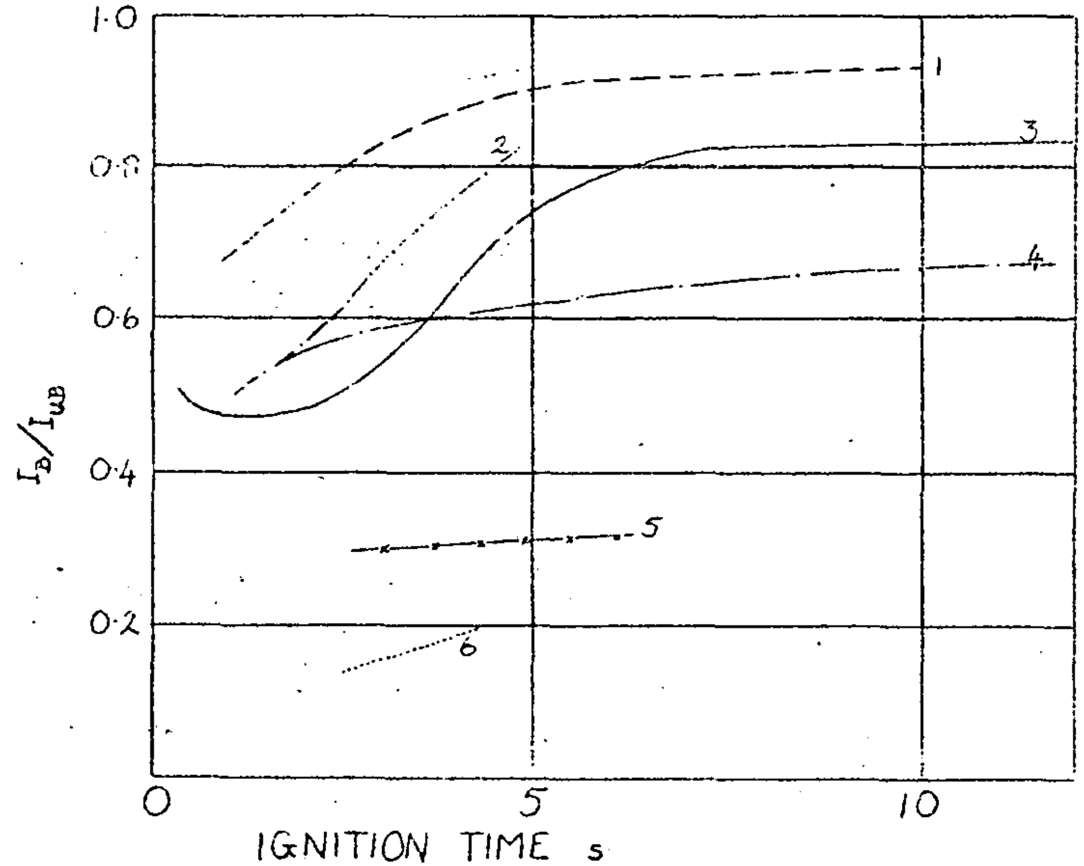

FIG 1 COMPARISON OF INTENSITY TO IGNITE BLACKENED (I_B) AND UNBLACKENED (I_{UB}) SPECIMENS WITH CARBON ARC SOURCE

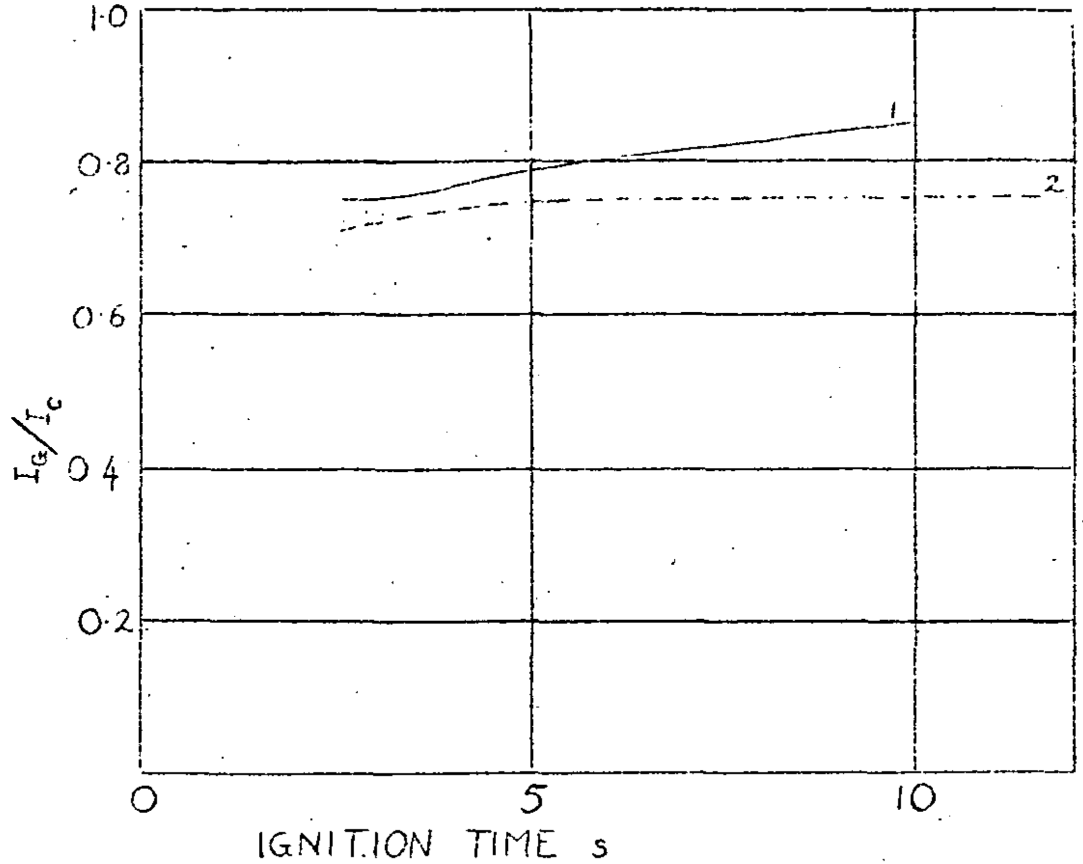

FIG 2 COMPARISON OF INTENSITY TO IGNITE GREEN (I_G) AND YELLOW OR WHITE (I_C) BLOTTING PAPER WITH CARBON ARC SOURCE

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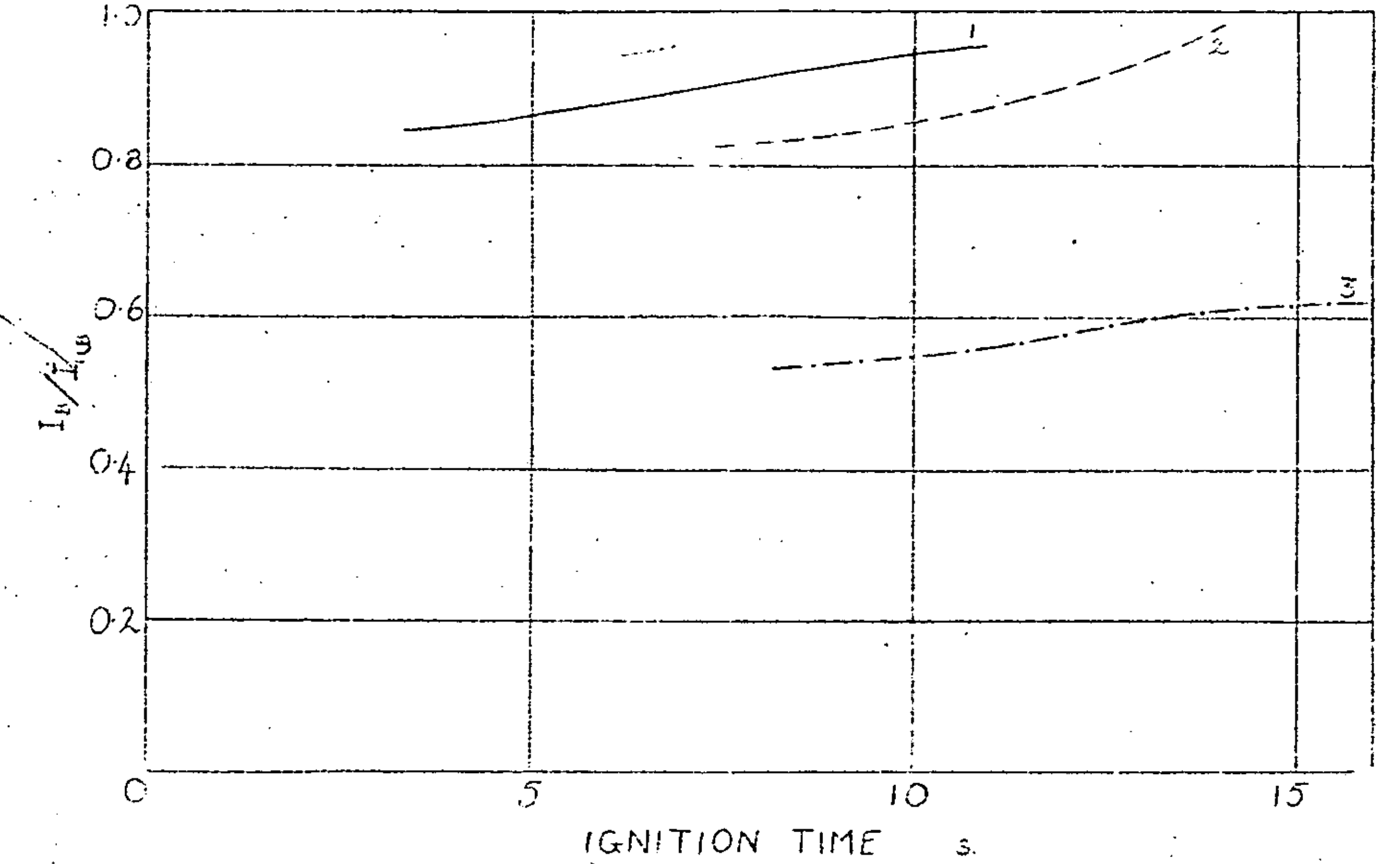

FIG 3 COMPARISON OF INTENSITIES FOR SPONTANEOUS IGNITION OF BLACKENED AND UNBLACKENED SPECIMENS (PANEL AND LAMP SOURCES)

———— (1) FIBREBOARD (panel source)
– – – – (2) COTTON (panel source)
–·–·– (3) OAK (lamp source)

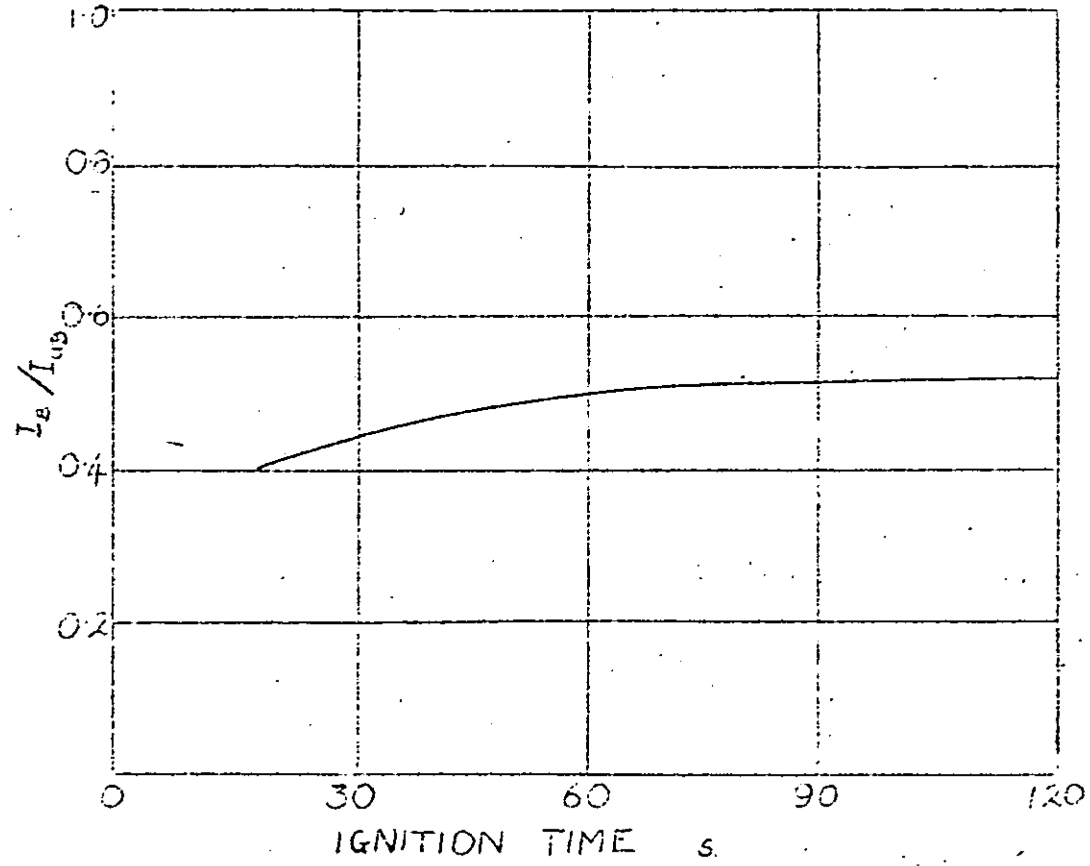

FIG 4 COMPARISON OF INTENSITIES FOR PILOT IGNITION OF BLACKENED AND UNBLACKENED FIBRE INSULATION BOARD WITH LAMP SOURCE

I_B Intensity for ignition of blackened specimen
I_{UB} Intensity for ignition of unblackened specimen