Fire Research Note
No.672

EXPERIMENTS ON THE RATE OF DECOMPOSITION OF WOOD IN FIRES

by

P. H. THOMAS

FIRE
RESEARCH
STATION

JULY 1967

Fire Research Station,
Borehamwood,
Herts.
ELStree 1341

F.R. Note No.672.
July, 1967.

EXPERIMENTS ON THE RATE OF DECOMPOSITION OF WOOD IN FIRES

by

P. H. Thomas

SUMMARY

This report summarises experimental results on the rate of weight loss of wood exposed to various levels of radiation, and the relation between the rate of burning of piles of wood and radiation in fully developed fires in compartments.

Estimates have been obtained of the amount of heat (calories) associated with the mass (gm) of decomposition.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

EXPERIMENTS ON THE RATE OF DECOMPOSITION OF WOOD IN FIRES

by

P. H. Thomas

1. Experiments on the rate of decomposition of wood heated from one side

Experiments have been conducted at Boreham Wood[1] to measure the rate of loss in weight of wood subjected to heat and a number of empirical formulae have been evaluated which can be used in certain situations to provide quantitative estimates of the rate of decomposition.

Samples of wood 12 cm x 15 cm were held vertically in front of a vertical surface, 30 cm square, which was maintained at a temperature of about 800°C and which exposed them to predetermined levels of radiation in the range 2-5 W/cm^2, the ambient conditions being about 20°C. As might be expected the rate of weight loss varied slightly with time and with wood density but another effect has been found. If an impermeable layer was placed parallel to the exposed surface within the wood, or if the edges of the specimens were sealed to make them more representative of larger heated areas, the rate of weight loss was less than when there was no such impermeable layer or no such sealing. When different species of wood were exposed, the observed rates of weight loss varied with the value of the permeability along the grain. The lower the permeability the slower the rate of weight loss. Thus, in three different respects, reducing the effective permeability of the wood reduced the rate of weight loss.

Increasing the incident radiation raised the weight loss, particularly at the beginning of heating before there was a thick insulating layer of charcoal between the hot surface and the zone of primary decomposition. The reciprocal of the regression coefficient between the rate of weight loss per unit area $\dot{m}''$ and the rate of heating per unit area I has the important unit of calories per gram measuring the amount of <u>extra</u> incident energy required to produce an <u>extra</u> unit mass of decomposed material. This quantity varied in these experimental conditions from about 380 to 2000 cal/g dependent on the thickness of char and species, white deal having a particularly low value. At the beginning of heating the decomposition appears to be as readily accountable for on a mass basis as on a volume basis but later a volume basis appears to be preferable, that is, deep charring can be described as a velocity rather than the rate of weight loss. This is the same form as is often referred to in connection with fire resistance tests, viz, $^1/40$ in/min. Another difference between the early and later stages of decomposition was that the impermeable layer produced its major effect in reducing the rate of weight loss in the early stages. Unfortunately, it was not possible to measure the surface temperature in these experiments, so the rates of weight loss cannot be related to the net heat transfer, only to the gross heat transfer with cooling to a cool atmosphere. Calculations however suggest that the surface temperatures were in the region 400°C to 500°C, varying with the condition of exposure. The heat required to produce 1 gram of volatile fuel, allowing for the convection transfer, has been estimated and some values are given in Table I. Regression equations are given in Table 2.

2. The behaviour of cribs in compartment fires

There have been many experiments in which the behaviour of experimental crib fires in building compartments has been studied and, over a range of scale and experimental fire conditions, the radiation emitted from the window of a compartment containing a fully developed fire is highly correlated with the rate of burning; there is a simple proportionality between them. The radiation measured at the instrument must be corrected for the geometrical relationship of the window and the instrument, to give the radiation emitted by the window and this must correspond to an effective temperature of radiation inside the compartment and so to a radiation level within the compartment. This proportionality between radiation and rate of weight loss is shown by the experimental results in Figs (1) (2) and (3). Figure (1) shows some data obtained by Webster, Raftery[2] and Smith[3,4] for fires on model scale in cubical compartments with one side completely open. The vertical scale shows the maximum radiation from the window. The burning rate was usually fairly steady and all the results, except those for the 0.31 m cube, are average values during the time when the mass of the fuel fell from 90% to 60% of its initial value, i.e. $R_{90/60}$. For the 0.31 m cube the rates given are $R_{80/20}$. Also the thermal insulation of the 2.4 m cube was different because the walls were brick; the smaller compartments were all made of asbestos board. Various amounts of wood, in cribs of various designs, were used as fuel. The scatter in the data is not strongly correlated with any of the variations in the fire conditions so that the mean slope of 1650 **J**/g or 395 cal/g is a satisfactory representative value.

With cubes having one side completely open it is not possible to decide between floor and window area as the basis for normalising the rate of burning for different scales but there are other data which can be used to decide this.

Three laboratories in different countries exchanged three types of wood and did a repeat test, making 18 tests, all nominally identical except for the use of three woods. There were some experimental variations but from the design of the experiment it was possible to correct for systematic differences between laboratories and between woods. The remaining differences were small, but it was possible to find a very close correlation between those in the rate of burning and those in the radiation. The results are shown in Fig.(2) where the ratio of radiation per unit window area and rate of burning per unit window area is seen to be 1450 J/g or 350 cal/g. Since the window area was half the floor area it seems that the rate of burning should be expressed as per unit of window area for the two sets of data to agree. One of the interesting features of the data is that no comparable correlation could be found for the temperatures in this narrow range of temperature. This is thought to be because the thermocouples were insufficiently accurate. The results shown in Fig.(3), are for some full scale tests[5] in a compartment 7.7 m wide, 3.7 m deep and 2.9 m high with two windows 1.8 m high. In most of the tests the fuel consisted of various numbers of cribs of 4 x 4 cm sticks.

The results in Figs (1) (2) or (3) all exhibit a slope of 1450–1650 J/g (350–395 cal/g) and the higher figure refers to the data where only the maximum values of radiation were plotted. These values are less than those obtained in the direct experiments on the effect of heating rates on the burning rates (Table 3), but there is no reason why the two figures should be exactly the same in view of the difference in the conditions of a single piece of wood and the assembly of fuel, where, for example, the air around the sticks of wood is heated. There are several applications of this approach. The first is that it provides a direct connection between the exposure hazard from a fire in a compartment to some other building and the rate of burning of the fire itself and hence the fire resistance required in the compartment. The radiation can be related to a temperature so that we have a connection between the temperature of a compartment and the rate of burning of the fuel in it and its exposure hazard. So far this can only be done for a limited range of fire situations. It is known for example that the shape of the compartment has some influence on the behaviour of a fire in it. As further information is acquired on the extent and importance of these situations further work on the above lines will be required. Also the behaviour of cribs in the open is only crudely understood and because these are important experimental tools further work on the correlation of existing data is currently in progress.

References

(1) THOMAS, P. H., SIMMS, D. L. and LAW, Margaret. Department of Scientific and Industrial Research and Fire Offices' Committee Joint Fire Research Organization Fire Research Note 657/1967.

(2) WEBSTER, C. T. and RAFTERY, Monica M. ibid. Fire Research Note 401/1959.

(3) WEBSTER, C. T., RAFTERY, Monica M. and SMITH, P. ibid. Fire Research Note 473/1960.

(4) WEBSTER, C. T. and SMITH, P. G. ibid. Fire Research Note 578/1965.

(5) LAW, Margaret. Radiation from fires in a compartment. To be published.

TABLE 1

(Specimens unsealed at edges)

Wood	Oven dry density ρ g/cm^3	Permeability along grain μ cm^{2}s^{-1} atm^{-1}	Thickness cm	Wt g	Intensity I cal cm^{-2}s^{-1}	Rate of wt loss $\dot{m}''$ g cm^{-2}s^{-1} x 10^4				Estimated heat* input required to produce 1 gm of volatiles cal/g	
						5% loss	10% loss	20% loss	30% loss	10% loss	30% loss
Western Hemlock	0.34	10	2.45	155	0.5	2.7	4.3	4.1	3.6	1220	1500
				167	0.7	6.8	6.3	5.0	4.6		
				165	1.0	10.9	6.6	6.3	6.7		
Western Red Cedar	0.36	2	2.45	168	0.5	2.9	4.2	4.1	3.6	1340	1700
				167	0.7	4.8	5.3	4.6	4.1		
				170	1.0	8.5	6.4	6.1	5.6		
Podo	0.46	100	2.45	211	0.5	4.4	6.9	6.7	5.8	670	820
				202	0.7	9.2	9.1	7.7	7.4		
				204	1.0	9.2	9.2	8.4	8.7		
Douglas Fir	0.45	2	2.45	220	0.5	2.2	3.5	4.0	3.7	1420	1600
				202	0.7	4.3	5.6	5.4	5.0		
				199	1.0	7.7	6.8	5.8	5.7		
Larch	0.51	2	2.45	236	0.5	2.4	4.1	4.5	4.1	1250	1300
				230	0.7	4.6	5.8	5.5	5.6		
						Specimen ignited					
Abura**	0.59	2 x 10^3	2.1	235	0.5	5.0	7.5	7.4	6.9	430	620
				225	0.7	7.8	9.9	9.6	7.8		
				242	1.0	10.7	13.0	10.9	10.2		
Makore**	0.64	10^{-3}	2.1	252	0.5	2.5	3.9	4.3	3.5	1130	1500
				254	0.7	5.6	6.1	5.4	5.1		
				252	1.0	8.8	8.5	6.2	6.3		
Ash	0.65	10	2.45	296	0.5	3.5	6.4	7.3	6.8	530	600
				295	0.7	9.0	9.8	9.2	8.3		
				295	1.0	12.5	11.4	10.0	9.9		

*Assumed specific heat of volatiles = 0.5 cal g^{-1}degC^{-1} Surface temperature of wood and reradiation estimated.

**Rates given at 6% 12% 23% and 35% loss because specimens were thinner.

TABLE 2

Weight loss	Statistical regressions	
	$\dot{m}''$ g cm^{-2} s^{-1} x 10^4	$\dot{m}''/\rho$ - cm/s
5%	$12.9\ I + 0.53\ \log_{10}\mu$ $+ 5.3\rho - 5.0$ $\sigma = 1.3$	$27.6\ I\ 4 - 13.7\rho + 0.93\ \log_{10}\mu - 0.33$ $\sigma = 3.7$
10%	$7.3\ I + 0.75\ \log_{10}\mu$ $+ 11.3\rho - 4.45$ $\sigma = 0.97$	$14.7\ I + 1.45\ \log_{10}\mu + 2.73$ $\sigma = 1.9$
20%	$4.55\ I + 0.75\ \log_{10}\mu$ $+ 10.6\rho - 2.7$ $\sigma = 0.6$	$9.7\ I + 1.37\ \log_{10}\mu + 5.24$ $\sigma = 1.4$
30%	$5.5\ I + 0.65\ \log_{10}\mu$ $+ 9.53\rho - 3.13$ $\sigma = 0.5$	$11.6\ I + 1.2\ \log_{10}\mu + 3.34$ $\sigma = 1.45$

TABLE 3

	10% weight loss ≙ 4 mm char	30% weight loss ≙ 8 mm char
Q - based on $C_g = 0.5$ cal $g^{-1}\ {}^oC^{-1}$ 5 woods of low μ 3 woods of high μ Calculated from application of mass transfer theory to measurement	 1270 540	 1520 680
$^1/\frac{\partial \dot{M}''}{\partial I}$ - extra incident energy to produce extra fuel All 8 woods taken together - from direct measurement.	1370	1800

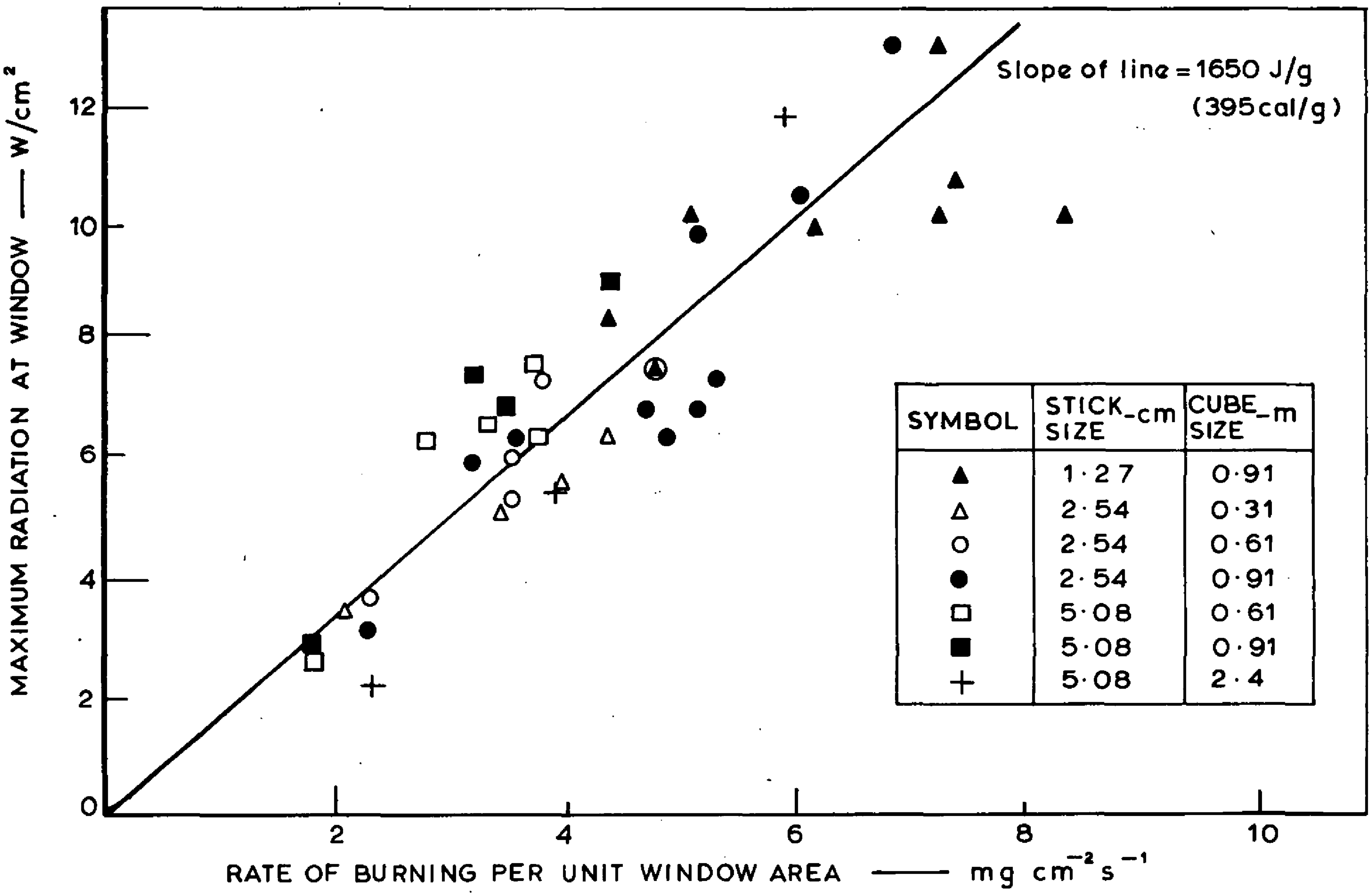
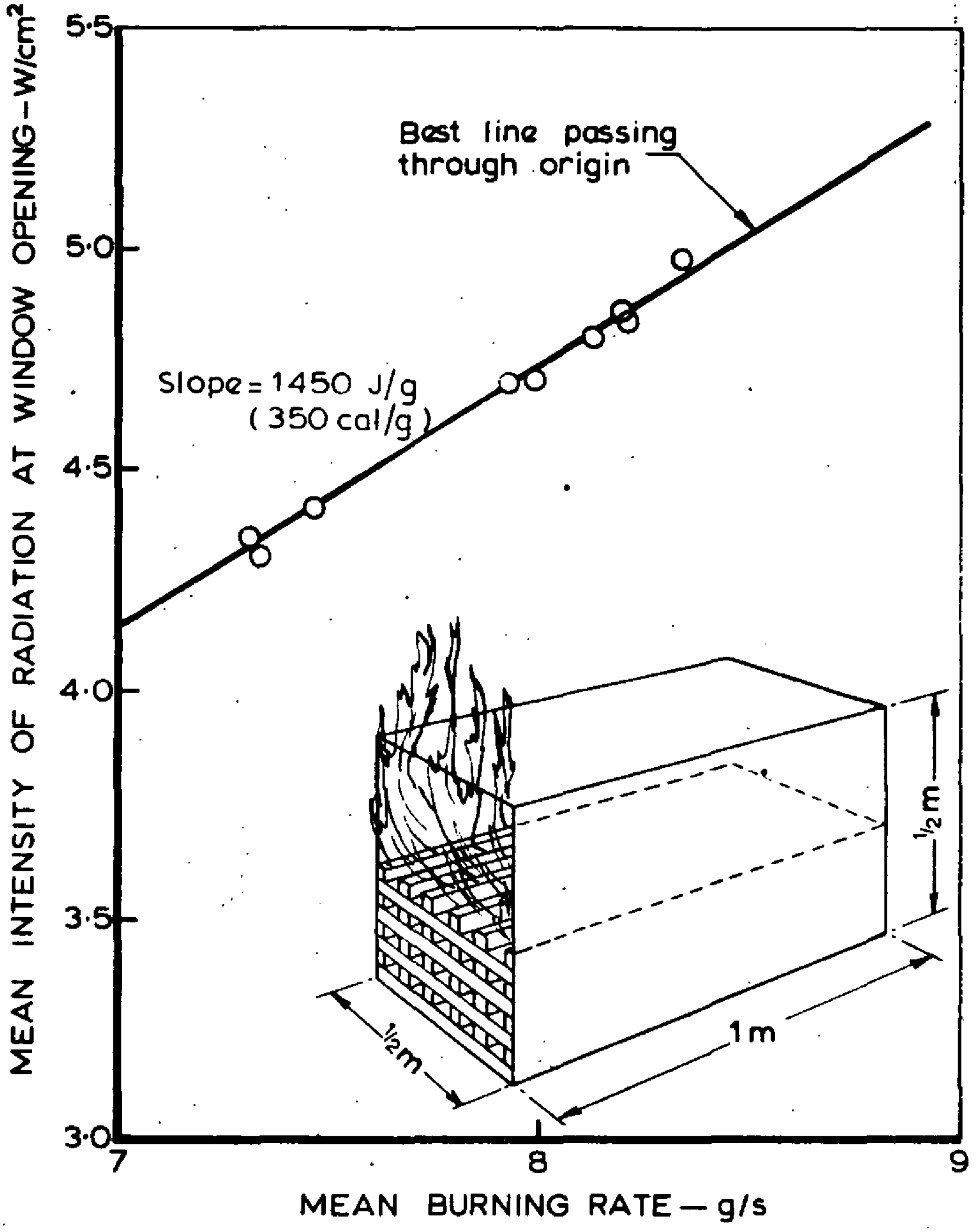


FIG.1. RADIATION FROM CUBES WITH ONE SIDE OPEN



Each result is the mean of a pair in a balanced set of data from three laboratories with three slightly different woods

FIG. 2. CORRELATION OF RADIATION AND BURNING RATE

1/7654 FR 672

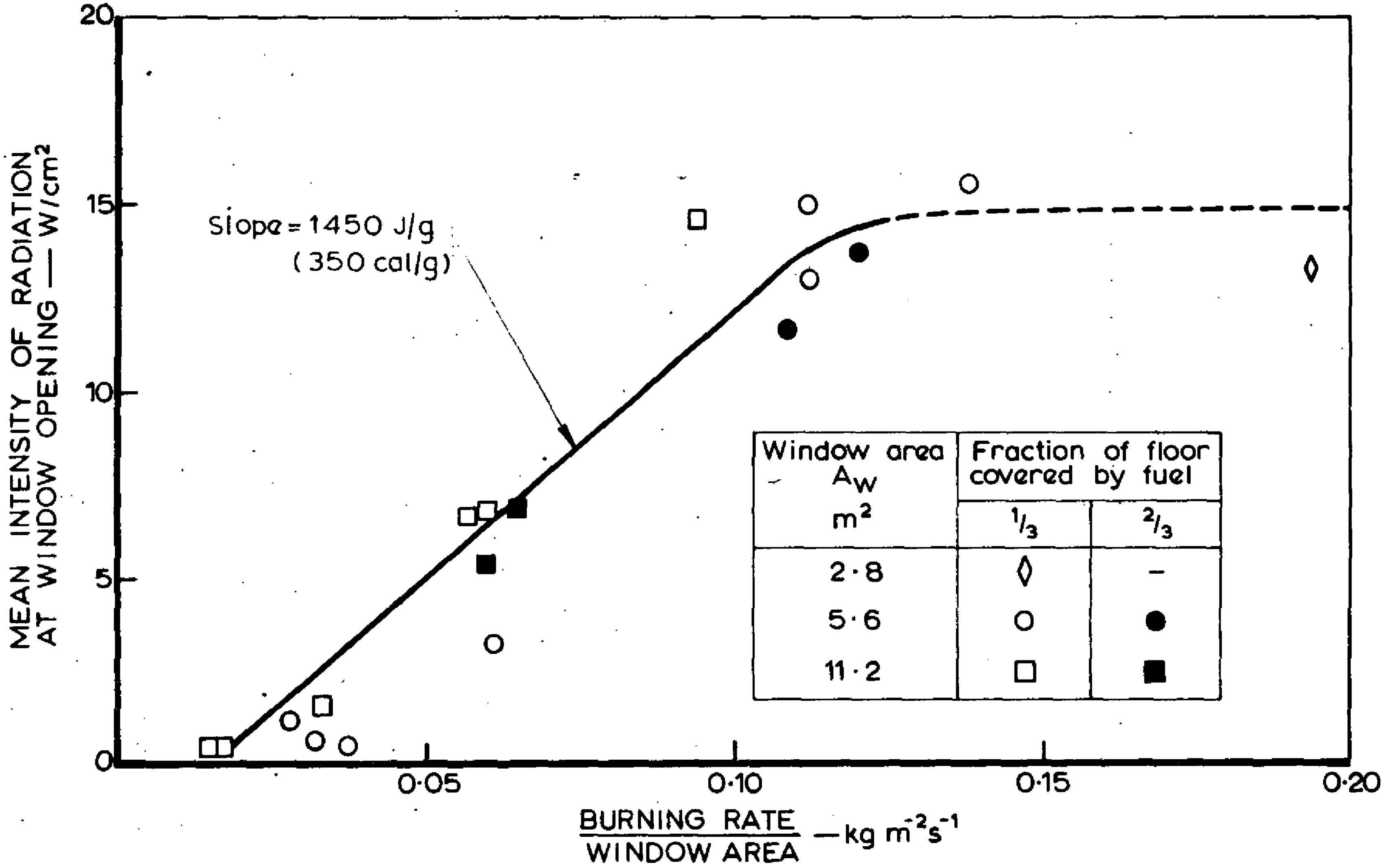


FIG. 3. BURNING RATE AND INTENSITY EMITTED FROM WINDOWS OF 7·7m x 3·7m x 3·0m COMPARTMENT