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Research Programme
Objective

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THE BURNING OF FIRES IN ROOMS, Part II.

Tests with cribs and high ventilation on various scales.

by

C. T. Webster and Monica M. Raftery

Summary

"Experiments on wood fires in cubical enclosures of 1 ft, 2 ft and 3 ft dimensions having one side completely open are described. Measurements of the rate of burning, the flame height above the enclosure, and the radiation from the fire were made for different fire loads. The various amounts of fuel in each case (fire load) were obtained by varying the height of the cribs; 1 in. sticks were used throughout, the horizontal stick spacing was kept constant at 3 in. In general over the range of these experiments, little scale effect was apparent".

May, 1959.

Fire Research Station,
Boreham Wood,
Herts.

THE BURNING OF FIRES IN ROOMS, Part 11.

TESTS WITH CRIBS AND HIGH VENTILATION ON VARIOUS SCALES.

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C. T. Webster and Monica M. Raftery.

1. Introduction

This report describes a further stage in a programme of experiments to study the rate of burning and other features of fires in single compartments. The first report (1) described tests in a 1 ft. cubical box with one side completely open and these showed that the burning of cribs of 1 in. wood was not markedly influenced by changes in the crib design. Accordingly experiments have since been made on larger scales with cribs of 1 in. wood and a constant horizontal spacing of 3 in. between the sticks. The effect of larger stick sizes and different ventilation conditions has yet to be considered.

For this work the method of ignition was changed to hasten the growth of the fire so that no part of the crib was burnt out before the whole crib was alight. The tests on a 1 ft. cube were therefore repeated for direct comparision, the burning rates obtained being only about 9% higher than previously.

2. Experimental arrangements.

For this series of tests incombustible boxes 1 ft., 2 ft. or 3 ft. cube were constructed of the same design and material as the 1 ft. cube box described in the previous report (1).

2.1. Weight loss measurements

The experimental procedure adopted for all tests to be described here was the same as for the earlier series of tests in the 1 ft. box.

The 1 ft. and 2 ft. boxes were suspended from a $\frac{1}{2}$ in. x $\frac{1}{2}$ in. cantilever and the 3 ft. box from a 1 in. x 1 in. cantilever. The cantilevers were held by a vice and projected 4 ft. from it.

The weight loss was recorded throughout the tests by the measurement of the change in resistance of strain gauges fixed to the cantilvers.

2.2. Radiation measurements during tests

The radiation from the flames above the box was measured during each test by a copper asbestos gold disc which was fixed in a central position 3 in., 6 in., or 9 in., above the box depending on its size and 2 in. behind the front plane of the box. The configuration of the flames with respect to the radiometer was thus close to unity for all the experiments.

The radiation from the box opening was measured by a copper asbestos disc placed on the centre line normal to the box opening and its distance from a box was varied to maintain a constant configuration factor between the opening and the radiometer.

2.3. Flame height measurements

The height of the flames above the box was observed against a graduated scale at various times during each experiment.

2.4. Type of wood and packing density of cribs

Pine wood conditioned at 65 per cent R.H., 65^{o}F, was used in all tests.

It was of 1 in. square section with unfinished surface and its density varied between 26 - 31 lb/cu.ft.

The length of stick varied with the box size and was 5/6th of the linear scale.

The weights of wood for tests were such that the fireload was nominally either 5, 4, 3 or 2 lb/sq.ft. of box floor area. The area of wood exposed in a crib was calculated by the formula given in the earlier report, (1) which allows for the variation in density.

2.5. Conditioning of boxes before test

Because asbestos wood is hygroscopic, the boxes were dried prior to each series of tests. For the 1 ft. box a gas flame was sufficient but for the larger boxes a burn-out, using a quantity of wood equal to the maximum fire load for that box, was carried out one hour before the commencement of tests.

2.6. Method of ignition

All the cribs were ignited by a sheet of ½ in. fibreboard covering quarter of the floor area under the centre of the crib and having 1.25 cc. of paraffin per square inch added to it. This produced rapid ignition for all tests. The additional weight of the igniting material was included in the weight of the crib.

3. Experimental Results

The principal results from the tests in the different size boxes have been tabulated (Table 1) and are shown graphically in Figs. 2 - 7.

3.1. Burning rates

The weight loss was plotted against time for all tests and the X-X curve in Fig. 1. is an example of the type of curve obtained. The curve can be divided into three sections, the ignition period of short duration where the burning rate is slow until the majority of the wood has been ignited, the central linear portion where the burning rate is approximately constant, and the burning out stage. The burning rates were calculated from the formula

$$R = \frac{W_{90} - W_{20}}{\Delta t}$$

where W_{90} = 90 per cent of the initial weight.

W_{20} = 20 per cent of the initial weight

Δt = time during which this percentage weightloss occurred.

This method of estimating burning rates covers the portion of the curve where the rate is constant and this procedure was adopted to make the assessment of rates systematic for all tests.

The burning rates are shown as a function of the initial weight of wood in Fig.2. Fig.3. shows the variation in the rate of burning per unit area of exposed wood surface with fire load.

3.2. Flame and radiation from the enclosure

Flame heights were observed frequently and the radiation from both the flames above the box and the box opening was continuously recorded during each test. The maximum flame heights and the peak radiation from both the flames and the opening are shown in relation to burning rate per unit floor area in Figs. 5 - 7. The importance of the variable burning rate/unit floor area is that it represents a velocity of combustible gases per unit area in the boxes.

4. Discussion

4.1. Burning rates in relation to weight of crib

The variation of burning rates with weights of wood in the cribs or area of wood exposed is shown in Fig.2. and the trend is for rate to increase linearly as the weight or area of wood is increased. The relationship between rate and weight or area of wood is dominated by the results for larger boxes. Thus the line in Fig.2. corresponds to a rate of 0.78 mg. cm^{-2} sec^{-1} whereas the mean for the 1 ft box is 0.62 mg cm^{-2} sec^{-1}. In the smaller boxes the rate tended to a maximum value at the highest fireloads for that box. This is probably associated with the large height of the crib in relation to the box height. Under these conditions the access of air to the rear of the crib is reduced and the ventilation and overall burning rates are therefore relatively less.

Fig.3. shows the experimental values of the burning rate per unit area in relation to the fireload. The points are closer together because the same limited range of fireload has been used for all tests. The general trend is for the burning rate per unit area R/A_W to decrease slightly with increased fireload for all box sizes.

4.2. Crib height

The height of the crib in relation to the height of the box has some influence on the rate of burning. This was in fact suggested by the lower rate of burning obtained with the largest fireload in the 1 ft. box as described in the earlier report (1). Fig.(4) shows the rate of burning per unit area against the crib/box height ratio. There is less scatter than in the correlation with fireload presented in Fig.(3).

The results indicate that little increase of burning rate is to be expected on full scale from this effect. The intercept for an infinitely large box gives a rate of burning of about 0.85 mg.cm^{-2} sec^{-1} (i.e. about 0.043 in/min). This figure is only slightly higher than may be calculated from Fig.2., i.e. 0.78 mg.cm^{-2} sec^{-1}, about 0.039 in/min. A rate of 0.85 mg.cm^{-2} sec^{-1} is larger than the 1/40 in/min typical of fire resistance (2)(3) test but is of similar magnitude to the results obtained by Bryan and Folk for open cribs (4)(5).

In the previous series of experiments there was no apparent variation in the rate of burning per unit area with crib height except for the largest crib and the relation in Fig.(4) can therefore only be considered as an approximation but the error in an extrapolation to large scale appears to be small. Some experiments on large scale are being done to confirm this.

4.3. Maximum flame heights

The maximum height of flames above the box is determined by the maximum rate of burning and is dependent on the linear scale of the box from which they emerge. It correlates well with burning rate per unit floor area (R/A_F) Fig.5. The straight line shows a negative intercept. The value of this intercept is about $\frac{1}{3}$ the linear height of the box which is reasonable for the effective origin of the flames bearing in mind that air entrainment occurs on two sides in the open above the top of the box and on one side only in the box so that the intercept of $\frac{1}{3}$ corresponds to a plane $\frac{1}{3}$ the height of the box above the floor.

The positive intercept on the horizontal scale represents the maximum burning possible before measurable flames emerge.

4.4. Radiation of flames above the box

The maximum radiation intensities from the flames above the box show a linear relation with burning rate per unit floor area (Fig.6). The results show some scatter about this line but it is not systematic with regard to scale.

The peak radiation from the flames usually corresponded in time to the maximum flame height and occurred during the linear portion of the weight loss/time curve for all tests.

4.5. Maximum radiation from the box opening

The maximum radiation intensities from the box opening, which are dependent on the highest temperature attained in the burning cribs, are given in Table 1 and they increase linearly with increasing rate of burning per unit floor area for all tests (Fig.7). With tests in the 1 ft. box the maximum radiation from the opening corresponded to the glowing charcoal stage in the burning crib when about a quarter the initial weight of wood remained and the maximum rate of weight loss had already occurred. In the 2ft. and 3ft. boxes the maximum radiation from the opening occurred at an earlier stage while the burning rate was still at a maximum, and when approximately half the initial weight of wood had been burned and flames were still emerging from the box.

5. Conclusions

A series of tests has been carried out in which wood cribs were burnt in various sizes of boxes. For these experiments for which the type and thickness of wood was not varied, the burning rate, the height of the flames above the box, and the intensity of the radiation from both the flames and the box opening, have been measured and show little scale effect.

The results indicate that it may be possible to extrapolate to higher values the variables that show good correlation for these experiments but tests will have to be carried out under full-scale conditions before the effects of scaling can be established as there are certain features of the burning, e.g. the time at which the radiation is a maximum which do show a scale effect.

Acknowledgement

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References

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TABLE 1

DESCRIPTION OF CRIBS AND PRINCIPAL EXPERIMENTAL RESULTS

Box Size	Test No.	Weight kg. (W)	Weight lb.	No. of sticks	Rate of weight loss g/sec (R)	Rate of weight loss lb/min.	Duration of rate of weight loss sec. Δt.	Crib height cm.	Crib height in.	Flame height cm.	Flame height in.	Max. radiation from flames cal.cm.$^{-2}$ Sec.$^{-1}$	Max. radiation from opening cal.cm.$^{-2}$ sec.$^{-1}$	Area of wood exposed cm.^{2} x10^4 (A_W)	Area of wood exposed ft.^{2}	Rate/area of wood exposed Mg.cm.$^{-2}$ sec.$^{-1}$ (R/A_W)	Rate/area of wood exposed lb.ft.$^{-2}$ min.$^{-1}$ x 10^{-2}	Fire load g.cm^{-2}	Fire load lb.ft.$^{-2}$	Density of wood g/cm^3	Density of wood lb./cu ft.
Tests in the 1' box, length of stick = 10 in.																					
1 ft	99	2.38	5.25	32	4.01	0.53	414	28	11	61	24	0.19	0.84	0.72	7.78	0.556	6.52	2.56	5.25	0.45	28
	100	1.98	4.25	26	3.63	0.48	375	22.8	9	53.4	21	0.18	0.74	0.59	6.32	0.615	7.59	2.08	4.[illegible]	0.45	28
	101	1.45	3.2	20	3.18	0.42	324	17.8	7	45.7	18	0.175	0.67	0.45	4.86	0.707	8.64	1.56	3.2	0.45	28
	102	1.04	2.3	14	1.97	0.26	366	12.7	5	30.5	12	0.085	0.43	0.32	3.4	0.616	7.65	1.12	2.3	0.45	28
Tests in the 2' box, length of stick = 20 in.																					
2 ft	105	9.17	20.2	57	17.55	2.36	360	30.5	12	122	48	0.360	0.965	2.57	27.75	0.694	8.51	2.40	5.0	0.50	31
	106	6.99	15.4	44	13.85	1.83	354	24.1	9.5	91.5	36	0.270	0.985	1.99	21.4	0.696	8.55	1.83	3.9	0.48	30
	107	5.42	11.95	37	13.17	1.74	288	20.3	8	76.2	30	0.207	0.803	1.67	18.0	0.788	9.67	1.42	3.0	0.45	28
	103	4.99	11.35	37	12.93	1.71	279	20.3	8	91.5	36	0.210	0.710	1.67	18.0	0.775	9.50	1.31	2.8	0.42	26
	108	3.68	8.1	24	8.47	1.12	306	14	5.5	30.5	12	0.075	0.475	1.08	11.67	0.784	9.60	0.965	2.0	0.47	29
Tests in the 3' box, length of stick = 30 in.																					
3 ft	109	20.85	46	90	42.37	5.60	345	30.5	12	183	72	0.340	1.33	6.09	65.6	0.696	8.53	2.5	5.1	0.48	29.5
	111	16.33	36	68	40.55	5.36	336	22.8	9	152	60	0.251	0.855	4.60	49.6	0.882	10.80	1.95	4.0	0.51	30.5
	110	12.49	27.5	51	26.03	3.44	282	17.8	7	107	42	0.133	0.795	3.45	37.15	0.755	9.27	1.5	3.06	0.50	31
	112	8.05	17.7	33	18.77	2.48	300	12.7	5	45.7	18	0.035	0.425	2.23	24.05	0.841	10.30	0.965	1.97	0.50	31

FIG. 2 THE EFFECTIVE BURNING RATE

Tests in the 1' box

TABLE 1

DESCRIPTION OF CRIBS AND PRINCIPAL EXPERIMENTAL RESULTS

Box Size	Test No.	Weight kg. W	Weight lb.	No. of sticks	Rate of weight loss g/sec R	Rate of weight loss lb/min	Duration of rate of weight loss sec. Δt	Crib height cm.	Crib height in.	Flame height cm.	Flame height in.	Max. radiation from flames cal. cm^{-2} sec^{-1}	Max. radiation from opening cal. cm^{-2} sec^{-1}	Area of wood exposed cm^2 $\times 10^4$ A_W	Area of wood exposed ft^2	Rate/area of wood exposed R/A_W Mg. cm^{-2} sec^{-1}	Rate/area of wood exposed lb. ft^{-2} min^{-1} $\times 10^{-2}$	Fire load g. cm^{-2}	Fire load lb. ft^{-2}	Density of wood g/cm^3	Density of wood lb./cu ft.
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	107	5.42	11.95	37	13.17	1.74	288	20.3	8	76.2	30	0.207	0.803	1.67	18.0	0.788	9.67	1.42	3.0	0.45	28
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	108	3.68	8.1	24	8.47	1.12	306	14	5.5	30.5	12	0.075	0.475	1.08	11.67	0.784	9.60	0.965	2.0	0.47	29
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	111	16.33	36	68	40.55	5.36	336	22.8	9	152	60	0.251	0.855	4.60	49.6	0.882	10.80	1.95	4.0	0.51	30.5
	110	12.49	27.5	51	26.03	3.44	282	17.8	7	107	42	0.133	0.795	3.45	37.15	0.755	9.27	1.5	3.06	0.50	31
	112	8.05	17.7	33	18.77	2.48	300	12.7	5	45.7	18	0.035	0.425	2.23	24.05	0.841	10.30	0.965	1.97	0.50	31

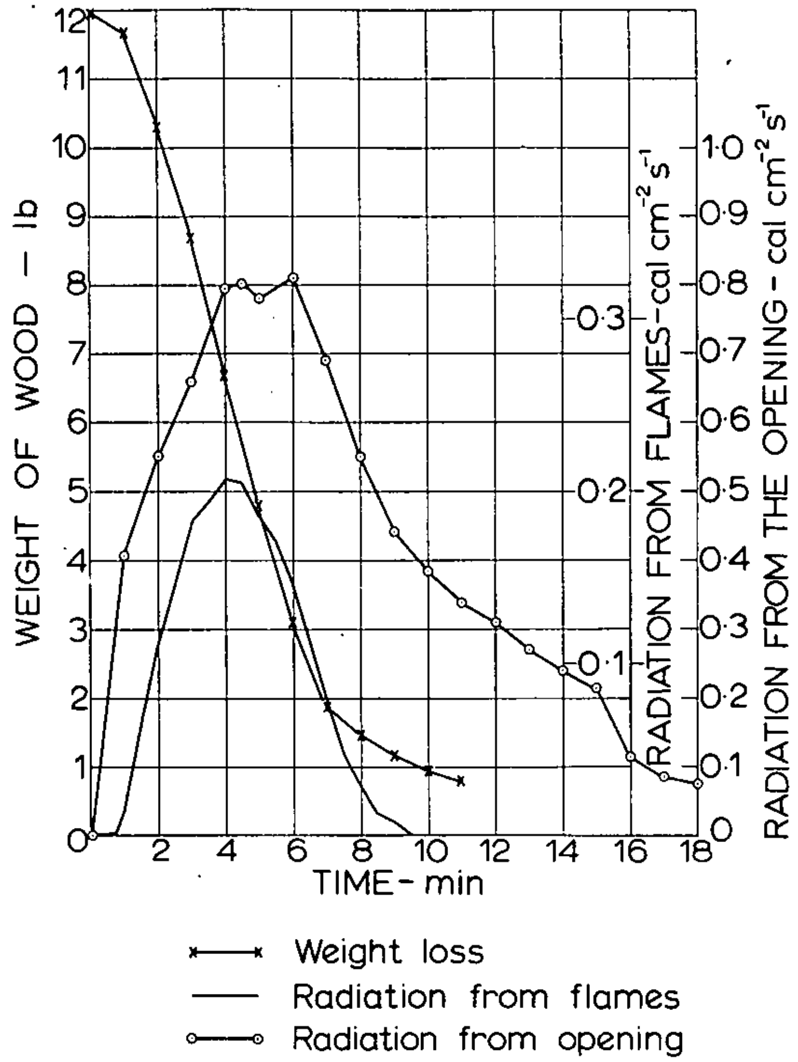

FIG. 1 VARIATION OF WEIGHT LOSS AND RADIATION WITH TIME IN A TYPICAL TEST

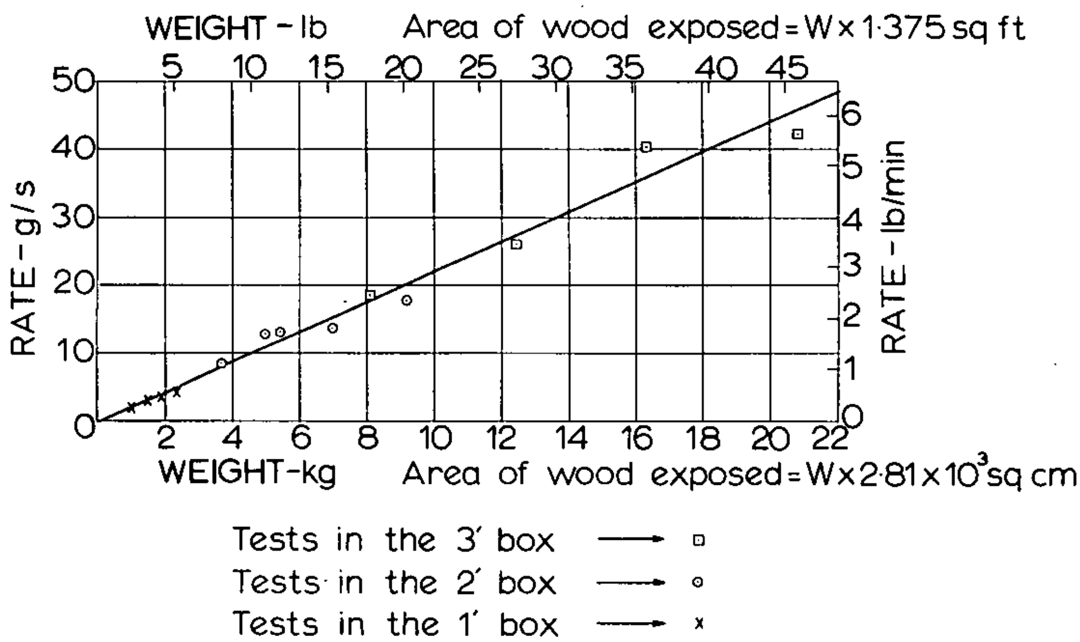

FIG. 2 THE EFFECTIVE BURNING RATE

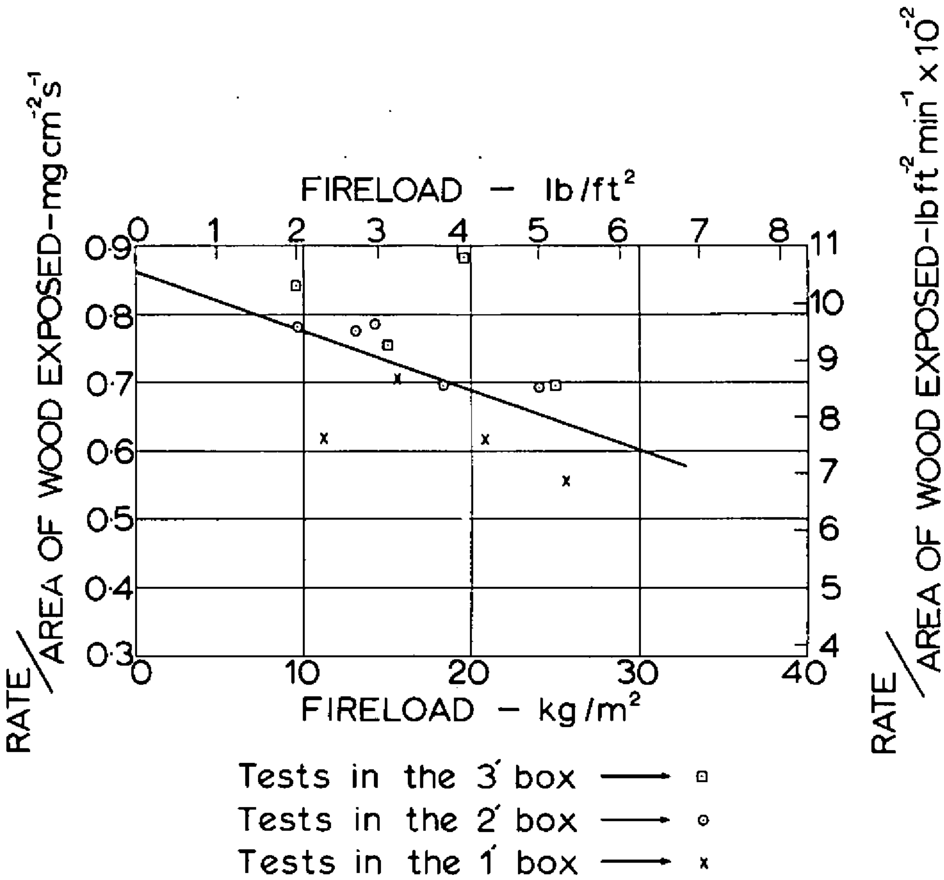

FIG. 3 EFFECT OF FIRELOAD PER UNIT AREA ON BURNING RATES

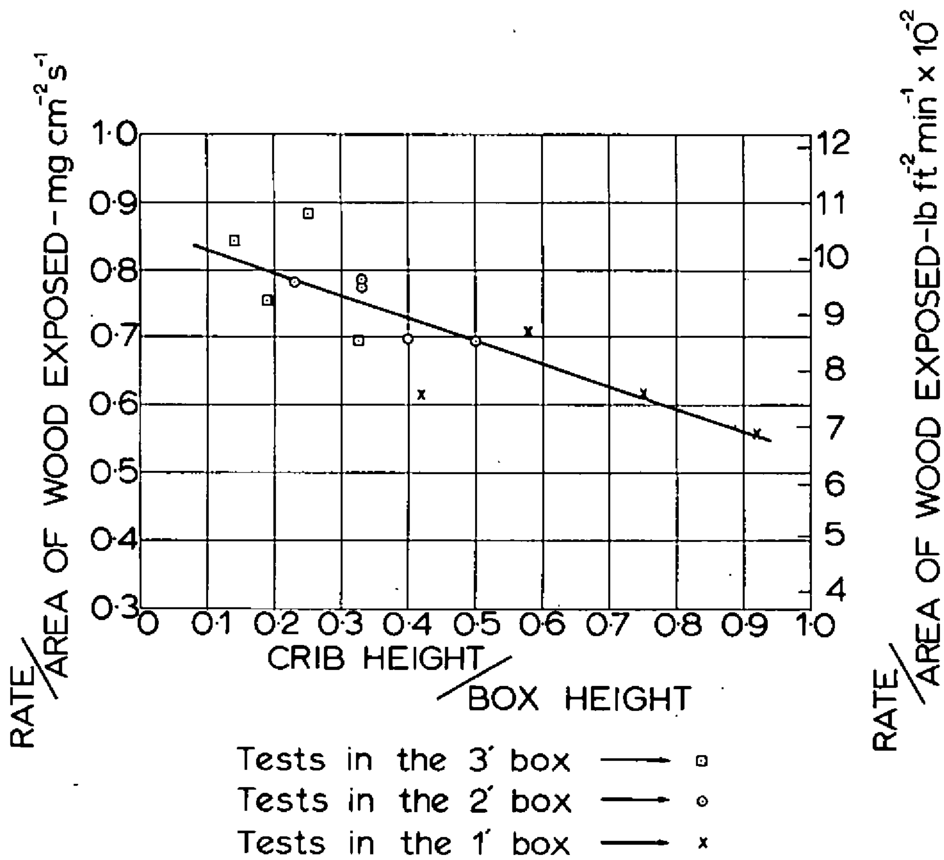

FIG. 4 EFFECT OF CRIB SIZE ON BURNING RATES

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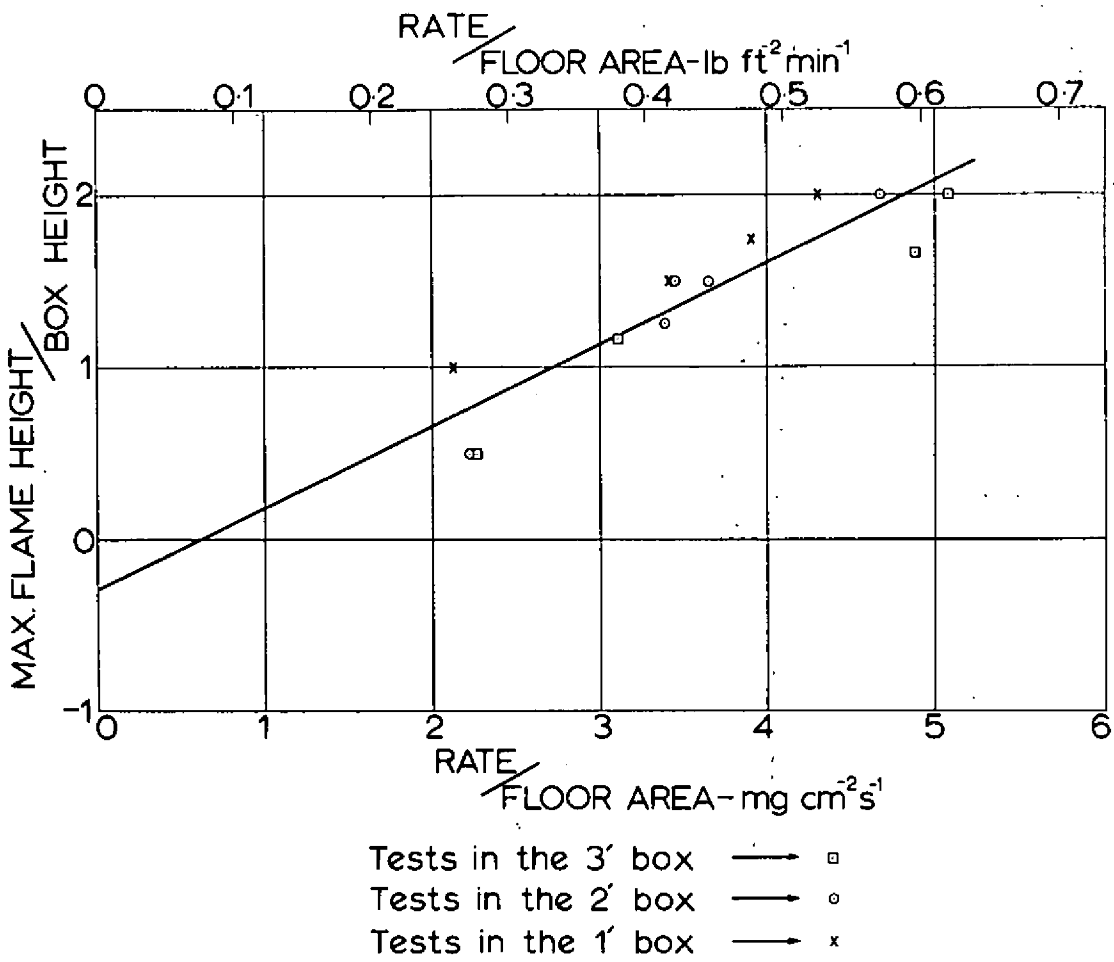

FIG. 5 THE MAXIMUM FLAME HEIGHT

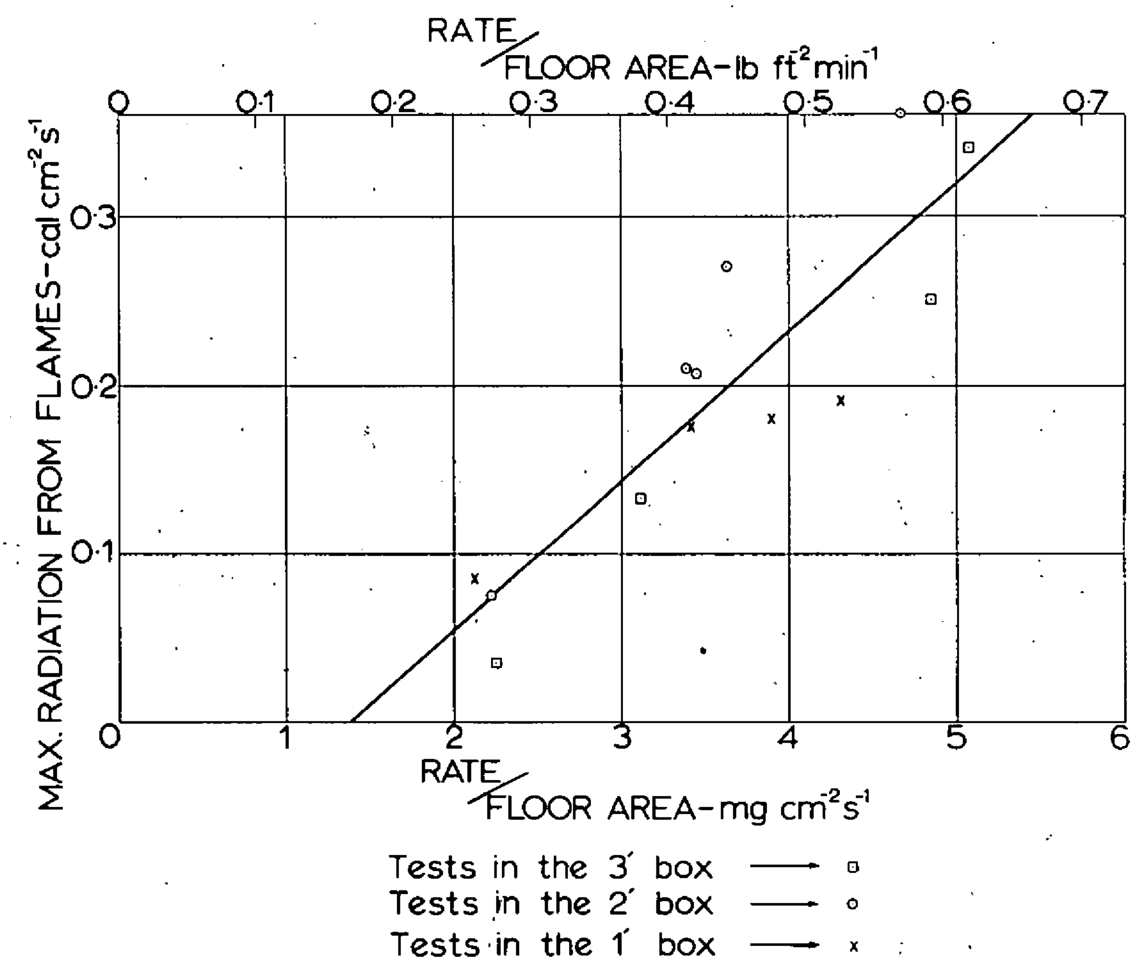

FIG. 6 THE MAXIMUM FLAME RADIATION

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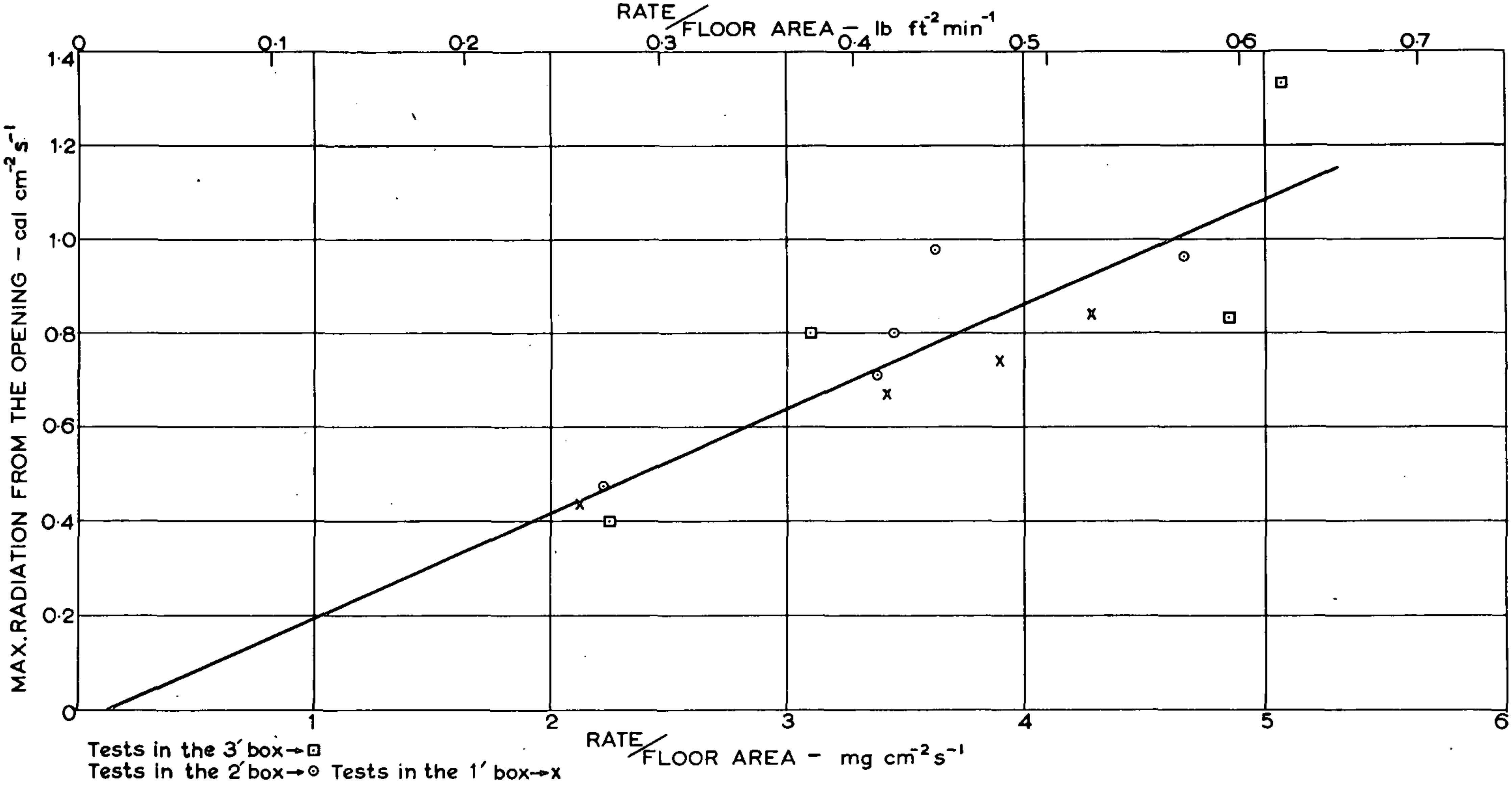

FIG. 7 THE MAXIMUM RADIATION FROM THE OPENING