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MISCELLANEOUS EXPERIMENTS ON THE BURNING OF WOODEN CRIBS

by

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1. Introduction

As part of a programme of research into the performance of sprinkler systems, it was necessary to design wooden crib fires having differing rates of development, in order that the effect of this factor on the response of sprinkler heads to a growing fire could be studied. This note describes experiments carried out to examine the effect of crib geometry on the rate of development of the fire resulting from ignition by a small source. The results are compared with other work, and the possibility of designing a fire of particular characteristics is examined.

2. Experimental procedure

The cribs were built on a square base, using white pine which was conditioned at a temperature of 65°F and relative humidity of 65 per cent prior to burning. The cribs were ignited at the centre of the base from a small source, consisting of a shallow circular tray in which 15 cc. or 30 cc. of methylated spirits was burnt, the quantity depending on the crib size. During burning the weight of the crib was measured continuously. Figure (1) shows typical curves of rate of burning, as measured by the rate of loss of weight, plotted against time, for crib fires developing at different rates.

3. Results

Cribs built of sticks of square section on a square base require only four parameters to define their geometry, these are, b, the side of the stick section, l, the stick length, n, the number of sticks per layer, and N, the total number of layers. Details of the geometry of the cribs are given in Table I, together with the maximum burning rates, and the times to attain the maximum rate from ignition.

The curves of burning rate plotted against time have a region which is almost linear (see Figure (1)), and which occurs for values of burning rate between approximately 45 and 75 per cent of the maximum. The slope of this linear portion is approximately equal to the maximum rate of development of the fire, (i.e. the maximum rate of change of burning rate) and its value is given in Table I.

3.1. Maximum burning rate

The cribs detailed in Table I vary in weight by a factor of about 30 to 1. In order to compare the burning rates, the maximum burning rate was expressed as a percentage of the original crib weight burnt per second.

Gross[1] has carried out experiments on the burning of wooden cribs of similar geometry, and has deduced a simple empirical correlation between the percentage maximum burning rate and the stick size, which forms a convenient basis for the prediction of any desired maximum burning rate. Gross found that when the percentage maximum burning rate (r) is plotted against the stick width (b), all the points lie on or below the curve $rb^{1.6} = 0.62$.

The exponent of 1.6 for b is supported by experimental[2] and analogue measurements[3][4] of heat conduction.

In the present work, if r is plotted against b on logarithmic scales, as in Figure (2), it is found that the relationship $rb = 0.62$ gives a good correlation of the results. In view of the evidence in favour of a power of 1.6 for b discussed above, it is more reasonable to fit a line of slope 1.6, on logarithmic scales; the line so obtained had the equation $rb^{1.6} = 1.02$ indicating burning rates significantly higher than those observed by Gross. The line was arranged to fit the results for cribs built of 2 cm. and 1 in. sticks, for which the majority of the results were obtained. The results for cribs constructed of $\frac{1}{4}$ in. and $\frac{1}{2}$ in. cribs lay below the line, although it should be noted that there were only two results for $\frac{1}{4}$ in. sticks. Although the 2 cm. and 1 in. stick sizes are not very different dimensionally, the observed percentage maximum burning rates differ significantly.

The curve $rb^{1.6} = 1.02$ is a limiting one, in that it represents the maximum percentage burning rate for a freely burning crib, built of sticks of a particular size, and whether a fire lies on or below the curve depends on the crib configuration. Burning at a rate which is less than the maximum given by the curve, arises from limitation of air or gas flow by the crib configuration. A measure of this limitation can be obtained by defining a suitable porosity factor for the crib. Gross has defined a porosity factor, ϕ, which provides a correlation of his results, which is given by:-

$$\phi = N^{0.5} b^{1.1} A_v/A_s \qquad \ldots\ldots\ldots (2)$$

where $A_v = (1-nb)^2$, is the initial open (vent) area of the vertical shafts,

and $A_s = 2nb\,(2l-nb)N+(N+n)b)$, is the initial total exposed surface area of the sticks.

The exponents given in equation (2) were presumably obtained empirically by Gross; the expression was applied to the present work, however, to see if similar trends were apparent. Values of A_V and A_S, together with values of ϕ, are given for each crib in Table I.

Figure (3) shows the function $rb^{1.6}$ plotted against ϕ for all the cribs. The points can be assigned to two distint regimes (as in Gross's results), a regime in which combustion is limited, below a critical value of ϕ, where the scaled rate of burning ($rb^{1.6}$) is proportional to the porosity factor ϕ, and a second regime corresponding to free combustion, where the scaled rate of burning is independent of the porosity factor. The values of $rb^{1.6}$ for the free combustion regime are larger than those obtained by Gross. The number of cribs at lower values of ϕ was limited, so that the slope of the line representing the limited combustion regime is not precisely defined, but the evidence points to a smaller slope than that of Gross. There is a group of points for stick widths of $\frac{1}{4}$ in and $\frac{1}{2}$ in which are anomalous in that they do not lie in either regime, although they would be expected to be freely burning cribs. More results at the small stick sizes are required to resolve this point.

Values of $rb^{1.6}$ were plotted against the ratio A_V/A_S alone, but no satisfactory pattern emerged. When the function $rb^{1.6}$ was plotted against $b\,A_V/A_S$, however, two regimes were discernible, as in Figure (3), and in fact the result was more satisfactory in that there were fewer anomalous points.

3.2. Rate of development

In the work on sprinkler systems it was necessary to have fires developing at different rates but with approximately equal maximum burning rates. The relationship $rb^{1.6}$ = const. can be written in the form R = const. x n N l $b^{0.4}$, for freely burning cribs, where R is the absolute maximum rate of burning. It is therefore possible to build a crib of the required size to attain a chosen burning rate, having selected the stick width.

It was found that the rate at which the fire develops was most easily varied by changing the stick spacing. In general, as the spacing was increased, the rate of development became more rapid, as can be seen by a comparison of the curves in Figure (4). A change in spacing, i.e. in the value of (n), also affects the maximum burning rate, and to maintain a chosen rate it is necessary to change the number of layers (N) or the stick length (1). It should be noted that a change in N also affects the rate of development, as seen by comparing cribs 15 and 16 in Table I, the burning curves of which are shown in Figure (5). This is confirmed by the burning rate - time curves for cribs 7-12, all of which have the same stick size and number of sticks per layer, but differing numbers of layers. Although there is some variation in the rates of development of fires which are of the same configuration there is a consistent trend towards more rapid development as the number of layers is increased. This is a result which would be expected on the simple assumption that the fire develops uniformly in a radial direction. Hence, if a change in the rate of development is required, while maintaining a constant maximum burning rate, the changes which are required in n and N are such as to be additive in their effect on the rate of development. For example, if a more rapid note of development was required, the value of n would be decreased, and so as to maintain a constant maximum burning rate, the value of N would have to be increased. The increase in the value of N would also increase the rate of development.

If the spacing is reduced to obtain a lower rate of development, the crib may no longer be freely burning, and the relationship R = const. x N l $b^{0.4}$ x ϕ will be applicable. In this case, the increase in maximum burning rate which would result from an increase in n with a freely burning crib, is opposed by the reduction in porosity, i.e. by a smaller value of ϕ.

If a rapid rate of development is required, while maintaining a constant maximum burning rate, then sticks of smaller width can be used. This enables the size of the base to be kept within reasonable limits, i.e. n can be kept to approximately the same value as with larger sticks at smaller spacings, and 1 can be kept constant, the effect of $b^{0.4}$ being comparatively small for practical values of b. The results obtained suggest that smaller sticks produce a more rapidly developing fire with the other crib parameters unchanged, although more results are required to establish this point.

4. Conclusions

The results show that for cribs of approximately cubical form, the maximum burning rate can be related to crib geometry by empirical relationships of the form suggested by Gross. It is therefore possible to construct a crib which will have a chosen maximum burning rate.

The rate of development of a crib fire can be varied widely on an empirical basis by changing the stick spacing, accompanied, in certain circumstances, by a change in stick width. Such changes usually result in a change in maximum burning rate, but it is usually possible to maintain a constant maximum rate of burning, either by changes in the number of layers, or in stick length.

5. References

(1) GROSS, D. "Experiments on the Burning of Cross Piles of Wood", Journ. of Res., Nat. Bureau. Stands., 66C (2), 99-105, April-June 1962.

(2) American Society for Testing Materials, "Standard Methods of Fire Tests of Building Construction and Materials", ASTM Designation E119-58.

(3) ROBERTSON, A.F., and GROSS, D. "An Electrical Analogue Method for Transient Heat Flow Anlaysis", Journ. Res., Nat. Bureau Stands., 61 (2), 105-115, (1958).

(4) LAWSON, D. I., and MCQUIRE, J. H. "The Solution of Transient Heat Flow Problems by Analogous Electrical Networks". Inst. Mech. Eng. Proc. (A), 167, 275, (1952).

TABLE I

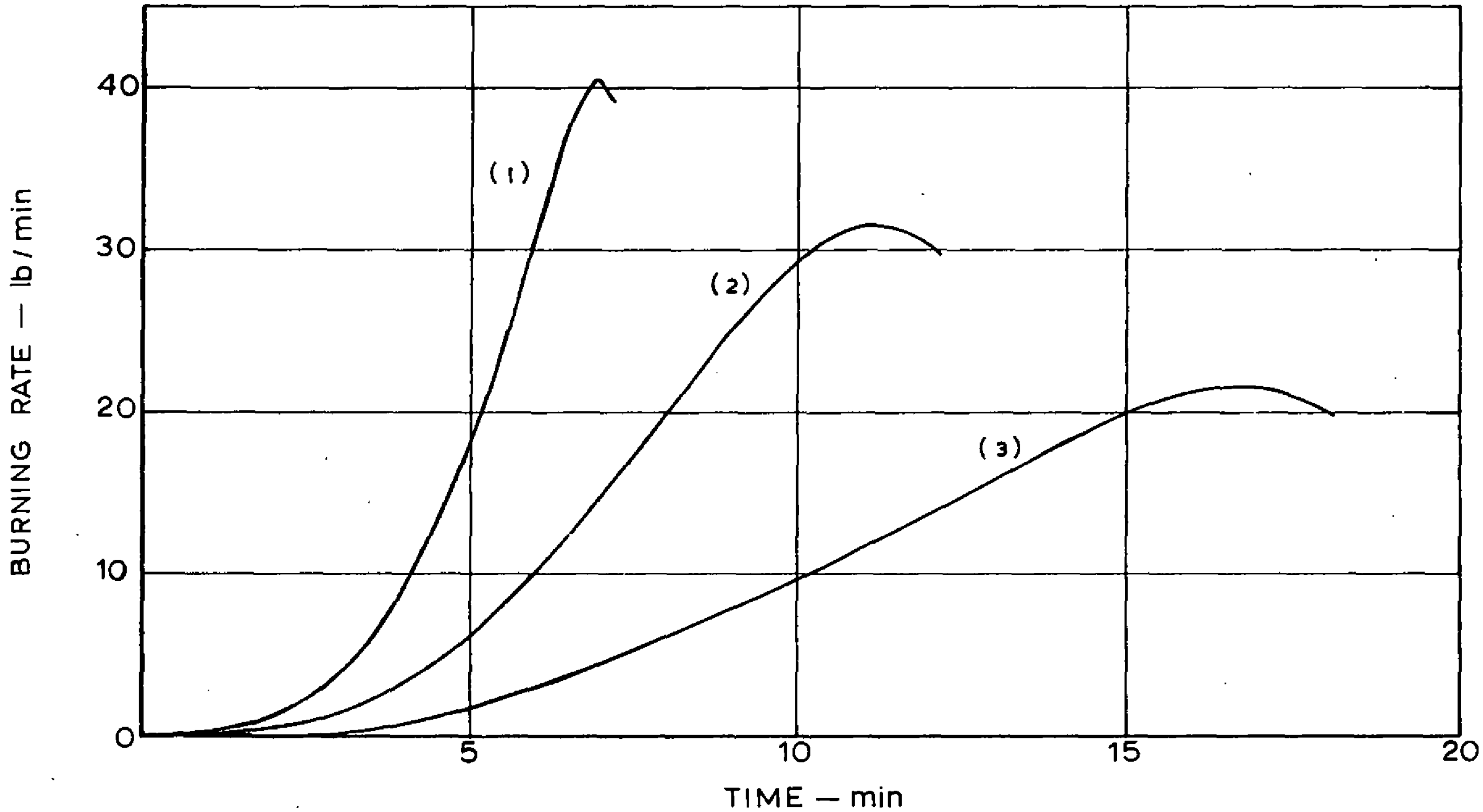
CRIB PARAMETERS AND BURNING RESULTS

Crib Ref.	Stick Size	Stick Length (in)	No. of Sticks Per Layer	Spacing Ratio (Approx.)	No. of Layers	Crib Weight (Lb)	Max. Burning Rate (Lb/Min.)	Percentage Max. Burning Rate (%/Sec.)	Time to Attain Max. Burning Rate (Mins-Secs.)	Time to Attain 60% of Max. Burning Rate	"Linear" Rate of Development (Lb/min2)	Initial Exposed Surface Area of Sticks (CM2)	Initial Open Area of Vertical Shafts (CM2)	Porosity Factor
1	2 cm.	24	15	1:1	8	32.5	2.5	0.128	15-30	12-00	0.45	46,920	906	0.118
2	"	24	15	1:1	16	65.5	5.0	0.127	21-30	16-30	0.75	92,040	906	0.0845
3	"	24	11	2:1	12	34.0	3.9	0.191	10-30	7-45	0.65	54,800	1520	0.206
4	"	24	11	2:1	12	34.0	4.0	0.196	9-30	6-59	0.65	54,800	1520	0.206
5	"	24	8	3:1	16	33.0	5.8	0.292	9-15	7-30	1.90	55,800	2020	0.310
6	"	24	8	3:1	16	33.0	5.7	0.288	9-00	6-54	1.45	55,800	2020	0.310
7(1)	"	16	5	4:1	8	7.63	1.31	0.288	5-10	4-37	0.18	11,928	903	0.392
8(1)	"	16	5	4:1	11	10.00	1.85	0.308	4-00	3-20	0.82	16,326	903	0.393
9(2)	"	16	5	4:1	8	7.25	1.40	0.322	3-40	2-42	0.41	11,928	903	0.392
10(2)	"	16	5	4:1	11	9.63	2.03	0.352	4-20	3-08	0.70	16,326	903	0.393
11(2)	"	16	5	4:1	20	15.20	3.57	0.391	4-10	2-39	1.35	29,520	903	0.294
12(2)	"	16	5	4:1	16	12.50	2.74	0.365	4-10	2-59	0.95	23,656	903	0.326
13	"	24	6	4:1	21	33.0	6.6	0.333	9-30	7-54	2.51	56,800	2400	0.415
14	"	24	6	4:1	21	33.0	6.8	0.344	7-45	5-57	4.75	56,800	2400	0.415
15	¼ in.	24	6	16:1	67	12.0	9.0	1.250	4-25	4-03	9.20	60,000	3270	0.272
16	"	24	6	16:1	134	23.0	13.8	1.000	3-45	3-15	12.60	127,900	3270	0.181
17	½ in.	24	16	2:1	13	20.0	3.2	0.266	8-45	6-24	0.65	55,000	1660	0.141
18	"	24	16	2:1	13	20.5	2.8	0.228	8-30	5-51	0.43	55,000	1660	0.141
19	"	24	10	4:1	20	19.5	5.4	0.461	6-00	4-56	2.00	56,500	2330	0.240
20	"	24	10	4:1	20	19.0	5.2	0.455	6-00	4-56	1.70	56,500	2330	0.240
21	"	24	6	8:1	34	18.0	8.8	0.815	5-07	4-44	6.20	67,000	2950	0.334

22	1 in.	36	17	1:1	24	228	18.6	0.136	17-10	14-15	2.20	298,000	2340	0.108
23	"	36	18	1:1	29	300	24.2	0.135	28-18	22-57	1.41	374,000	2100	0.0841
24	"	36	18	1:1	29	252	19.0	0.126	23-36	17-51	1.14	376,000	2100	0.0837
25	"	36	18	1:1	31	290	18.6	0.107	23-48	17-18	1.35	400,000	2100	0.0814
26	"	36	18	1:1	29	284	18.8	0.110	25-12	17-36	1.03	376,000	2100	0.0837
27	"	36	15	1½:1	33	284	27.0	0.159	16-42	13-54	2.06	374,000	2850	0.122
28	"	36	15	1½:1	32	289	21.6	0.125	16-00	11-18	2.20	364,000	2850	0.124
29	"	36	15	1½:1	32	273	21.6	0.132	16-30	11-36	2.20	364,000	2850	0.124
30	"	36	15	1½:1	32	287	22.1	0.129	17-00	11-42	2.00	364,000	2850	0.124
31	"	36	10	3:1	42	226	30.1	0.222	10-33	7-27	5.30	343,000	4380	0.232
32	"	36	10	3:1	42	235	31.8	0.226	10-39	8-12	5.28	343,000	4380	0.232
33	"	36	10	3:1	36	199	28.2	0.236	9-24	7-45	7.72	294,000	4380	0.250
34	"	36	10	3:1	36	202	32.0	0.264	9-45	6-42	4.17	294,000	4380	0.250
35	"	30	8	3:1	30	116	17.2	0.246	11-18	9-09	3.59	165,000	3120	0.289
36	"	24	7	3:1	24	64	9.4	0.245	8-36	6-57	1.87	91,800	1870	0.280
37	"	36	10	3:1	42	233	31.2	0.223	10-33	7-47	5.00	343,000	4380	0.212
38	"	36	10	3:1	42	232	31.6	0.226	9-54	7-20	6.80	343,000	4380	0.212
39	"	36	10	3:1	42	229	32.2	0.234	10-30	8-09	7.20	343,000	4380	0.212
40	½ in.	36	9	8:1	88	144	40.6	0.470	6-50	5-32	12.6	348,000	6410	0.224
41	"	36	9	8:1	96	150	43.5	0 483	6-40	5-28	15.9	379,000	6410	0.214
42	"	36	9	8:1	96	151	42.0	0.464	6-54	6-07	15.0	379,000	6410	0.214

(1) These cribs were ignited using three rectangular trays placed under the base sticks.

(2) These cribs were ignited using five rectangular trays placed under the base sticks.

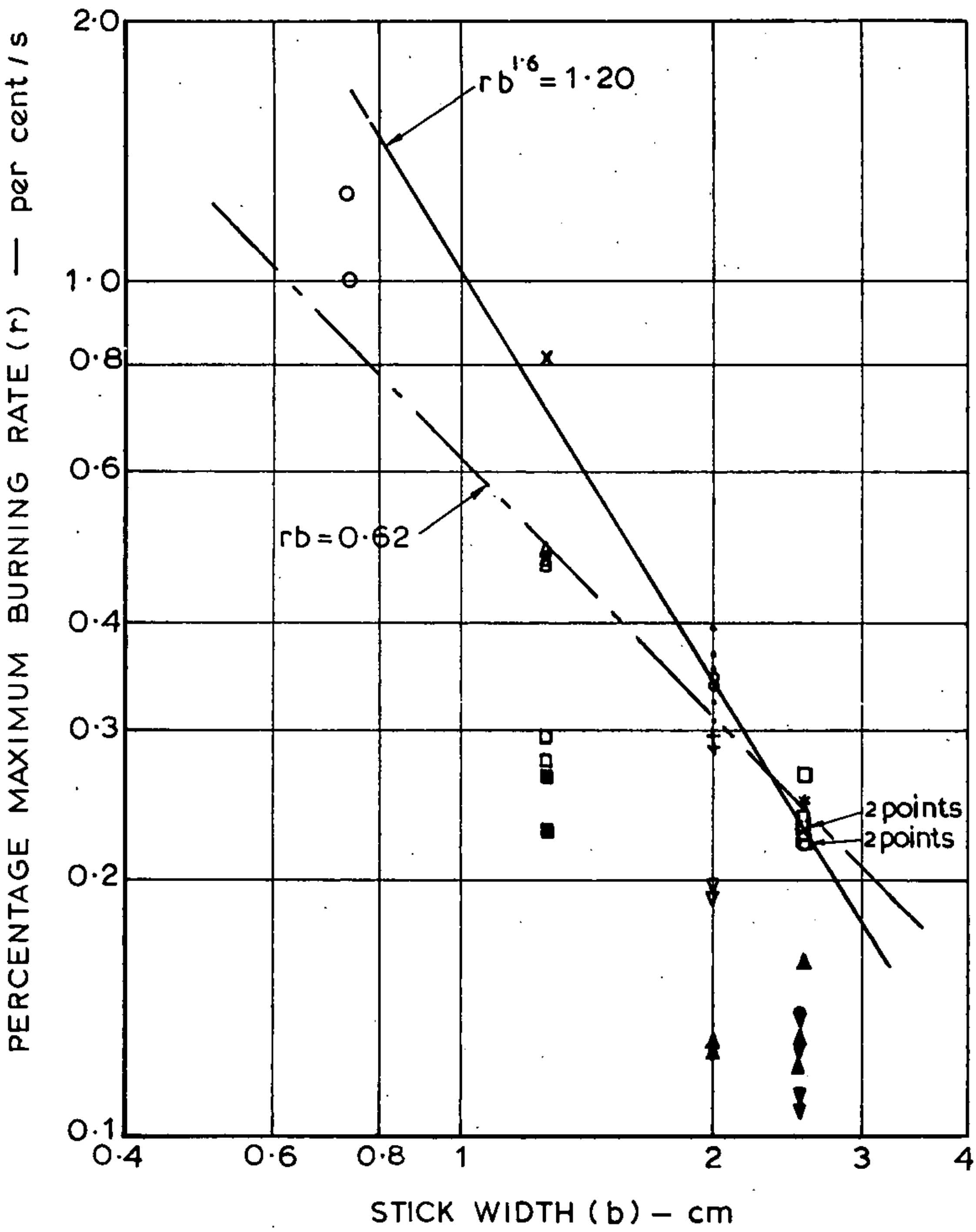


(1) b = $\frac{1}{2}$ in.
ℓ = 36 in
n = 9
N = 88

(2) b = 1 in.
ℓ = 36 in.
n = 10
N = 42

(3) b = 1 in.
ℓ = 36 in.
n = 15
N 32

FIG.1. TYPICAL CURVES SHOWING VARIATION OF BURNING RATE WITH TIME



	n	SPACING RATIO	CRIB REF
·	5	3·8:1	7-12
o	6	4:1 & 16:1	13,14 & 15,16
x	7	3:1	36
+	8	3:1	5, 6, 35
△	9	8:1	40-42
□	10	3:1 & 4:1	31-34, 37-39 & 19, 20
▽	11	2:1	3, 4
▲	15	1:1 & $1\frac{1}{2}$:1	1,2 & 27-30
■	16	2:1	17, 18
●	17	1:1	22
▼	18	1:1	23 - 26

FIG. 2. VARIATION OF PERCENTAGE MAXIMUM BURNING RATE WITH STICK WIDTH

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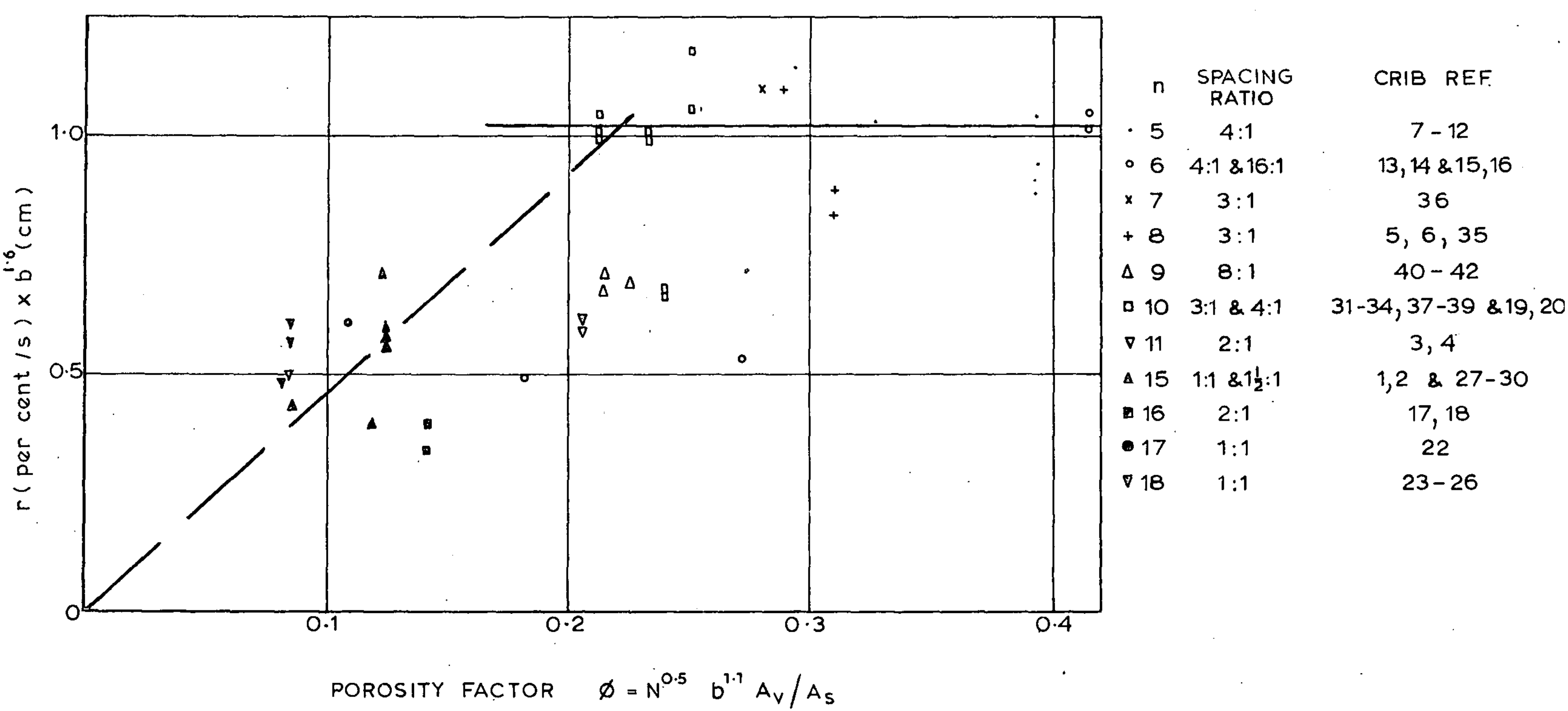
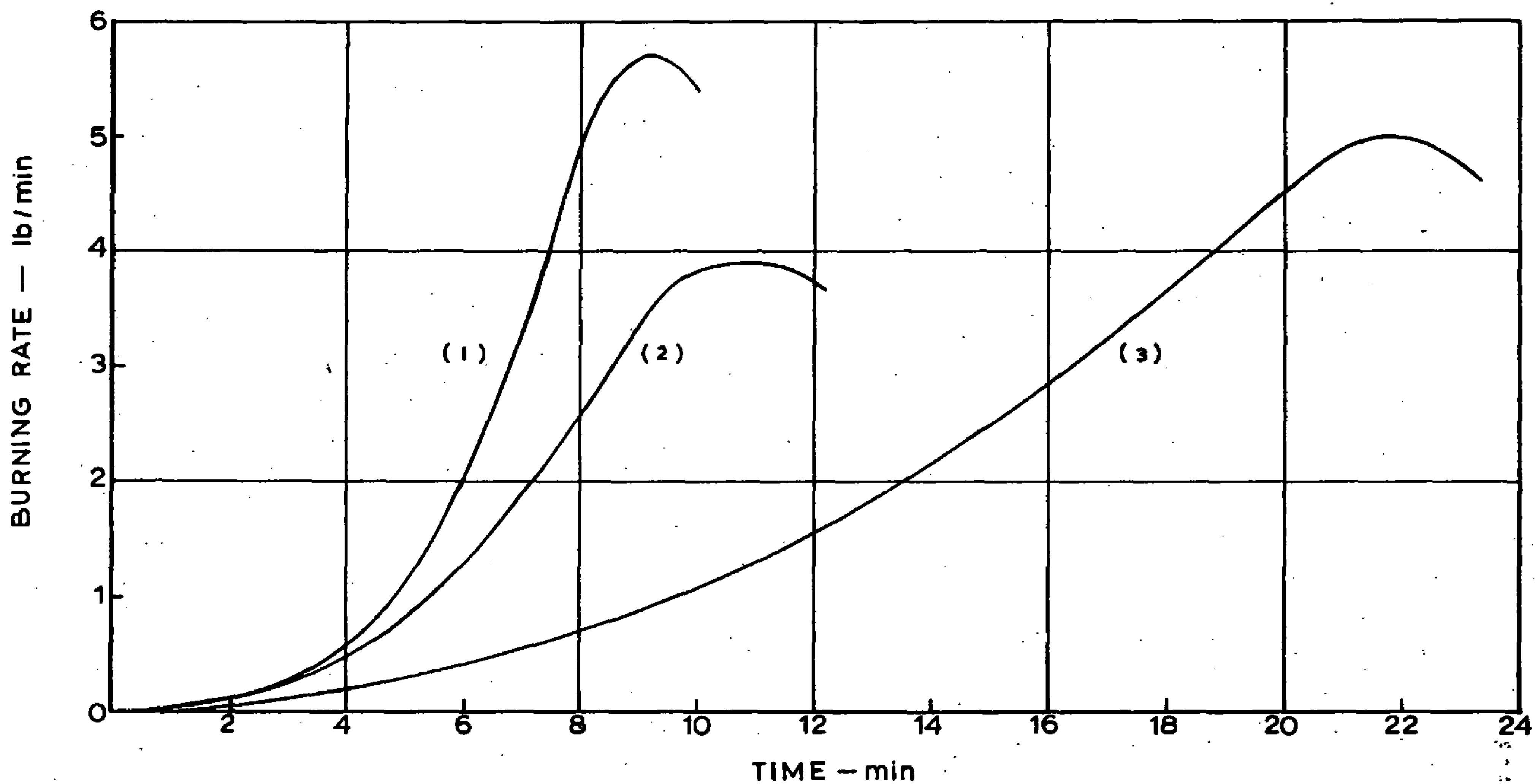


FIG. 3. RELATIONSHIP BETWEEN SCALED RATE OF BURNING AND POROSITY FACTOR



(1) n = 8 (spacing ratio 3:1) N = 16

(2) n = 11 (spacing ratio 2:1) N = 12

(3) n = 15 (spacing ratio 1:1) N = 16

ℓ = 24 in
b = 2 cm

FIG. 4. VARIATION OF RATE OF DEVELOPMENT OF CRIB FIRES WITH STICK SPACING

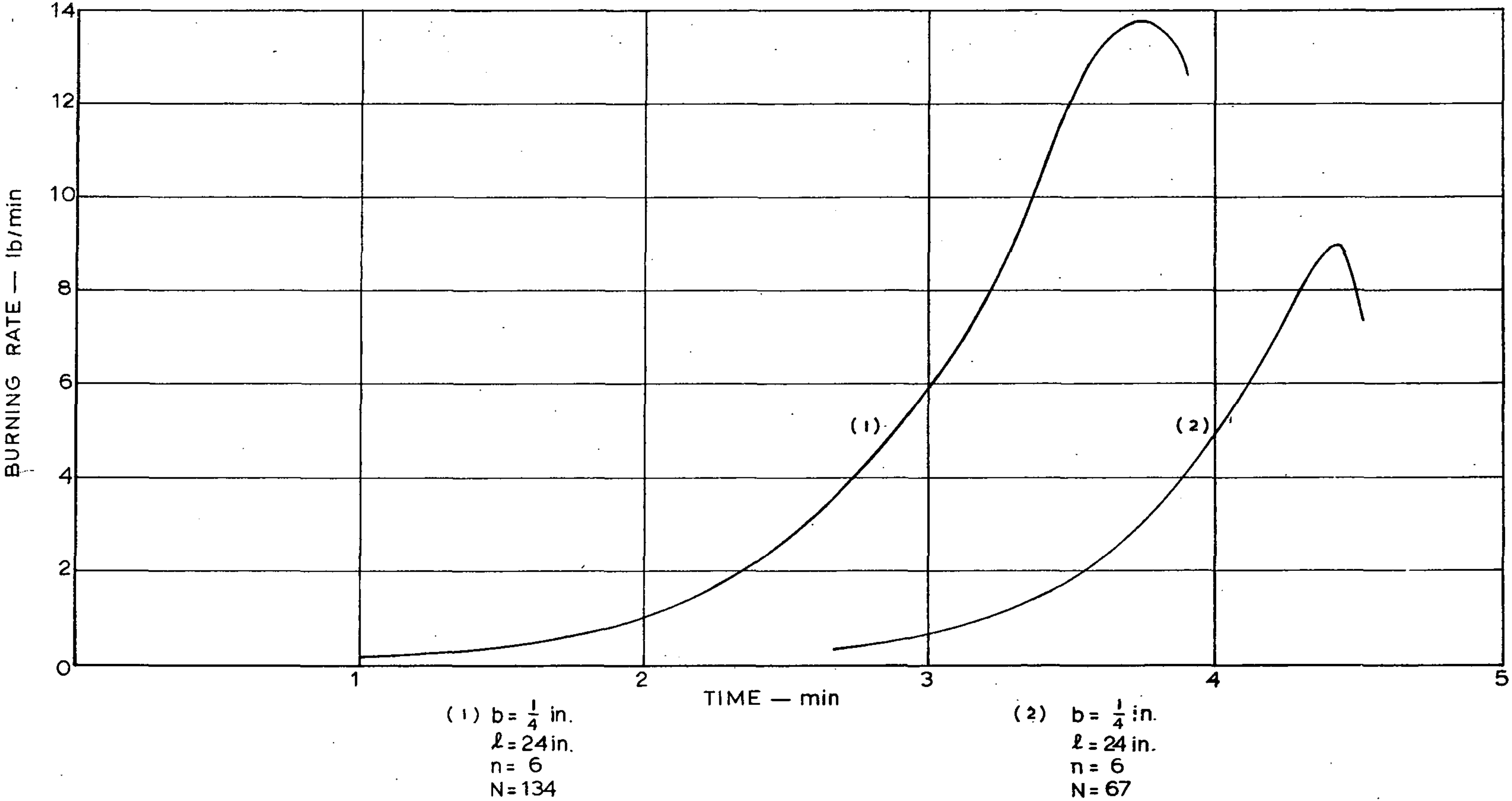


FIG. 5. EFFECT OF NUMBER OF LAYERS ON RATE OF DEVELOPMENT