F.R. Note No. 191/1955
Research Programme
Objective E4/3

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

THE AMERICAN FLAMMABILITY TEST FOR FABRICS COMPARED WITH THE SEMI CIRCULAR TEST

by

P. H. Thomas and H. Wraight

Summary

Two tests, the American standard test and the semi circular test, for the flammability of fabrics are compared with each other and with the speed at which flame spreads up a fabric hanging vertically. It is shown that the empirically derived correlation between measured vertical flame speed and the performance of the semi circular test can be used to correlate the two tests with each other.

Certain anamolies with the American test are discussed.

June, 1955.

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1. Introduction

In the United States an apparatus for determining the flammability of fabrics to be used on clothing, was accepted as a Commercial Standard in 1953 (1). This note describes work done to discover if any relation existed between the performance of materials on the above test and on tests developed at the Joint Fire Research Organization.

2. Description of American Flammability Test

A detailed description (1) of the American Test has been published: assentially the test consists of applying a butane flame $\frac{5}{8}$ in. long, for one second to the upper surface of a 2 in. x 6 in. specimen held in a frame at 45° in a ventilated box. The time taken for the flame to travel up the specimens and burn through a cotton thread 5 in. from the gas jet is recorded automatically. The gas jet was a hypodermic needle of external and internal diameters 0·028 in. and 0·018 in. respectively. Any material which takes less than four seconds on this test is considered for the purposes of the Standard to be of hazardous flammability.

For the programme of tests an apparatus was constructed similar to the American Flammability apparatus, except that a coal gas flame was used instead of a butane flame.

3. Experimental procedure

The number of specimens in each sample tested was usually ten. Five of them were dried in an oven at 105°C for thirty minutes and left to cool in a desiccator, and five were conditioned to be in equilibrium with an atmosphere at 22°F and 57 per cent relative humidity.

Tests were done on a wide range of materials, including cotton, silk rayon, wool and paper. Their performance on the American Flammability Test was compared with that on the Semicircular Test(2), and also with their vertical flame speed. The results obtained are given in Table 1, and Figures 1, 2, 3 and 4. With the specimens of natural silk, the flame travelled up the specimen on the American Test in under 4 seconds but was too small to burn through the cotton thread and thus operate the stopping mechanism. For this material, therefore, the time for the flame to reach the thread was measured, rather than the time to burn it. The equations used to calculate vertical flame speed from the results of the semi-circular tests were (2), (3).

$$V = 0{\cdot}078\,\frac{D^{5/2}}{T} \qquad \text{partial spread} \qquad \ldots\ldots (1)$$

$$V = \frac{1665}{T^{1{\cdot}03}} \qquad \text{complete spread round semi-circle} \qquad \ldots\ldots (2)$$

where D is distance of spread in cm
T is time in secs
V is vertical flame speed in cm/sec.

4. Discussion

4.1. Effect of conditioning

With all the specimens tested except natural silk B, chart paper, and wool cotton 20/80, it was found that the oven-dried samples burnt more quickly than the conditioned ones, as might be expected. The effect of oven-drying varies widely from one material to another in an apparently haphazard manner.

4.2. Comparison of tests

The relation between the time taken by materials on the American Test and the time to burn right round the semicircular frame test is shown in Figure 1. The results show that there is an approximately linear relation between the time taken on the two tests for this class of materials.

It is possible to use equation (1) to calculate vertical flame speed from the results of the American Test. The method is described in the Appendix and the relation obtained is

$$V = \frac{96}{T_A} \qquad \text{......} \ (3)$$

where V is vertical flame speed in cm/sec.
T_A time of spread in American Test in secs.

If this equation is compared with equation (2) it is seen that there should be an approximate proportionality between T_A and T_S

$$T_A \doteq \frac{1}{16} T_S \qquad \text{......} \ (4)$$

This relation is drawn in Figure 1 and it is seen to give a satisfactory correlation. Figure 2 shows the relation between observed and calculated vertical flame speeds for the semicircular test, Figure 3 a similar relation based on equation (3) for the American Test, and Figure 4 the relation between the two calculated vertical flame speeds for the two tests.

From Figures 2 and 3 it is seen that eight of the results with the semicircular test and eleven of the results with the American Test are more than 30 per cent too high. Two of these eleven are for the silks in which the time to reach the thread was measured instead of the time to burn the thread. This it is clear underestimates the time in relation to other fabrics thus overestimating the vertical flame speed, but the necessity for this approximation is a feature of the apparatus and the discrepancy must be counted as a bad feature of the American Test.

Apart from the results for natural silk it is seen from Figure 4 that the two tests give results more like each other than in either of the vertical flame speed measurements. That this is partly due to the use of an empirical equation derived for the test being modified for use with the other, does not detract from this view.

From equation (3) it would follow that the American Test is failed by those materials which have a calculated vertical flame speed above about 24 cm sec^{-1}. Except for natural silk only those materials which were graded below Class V on the semicircular frame test were found to fail the American Test by burning in less than 4 seconds.

4.3. Discussion of the American Test

When testing a 60/40 wool-cotton fabric, it was found that application of the pilot flame for only one second was insufficient to ignite the specimen, but that the latter will burn up with an application of longer duration. The time required for the pilot flame to ignite the sample is very critical and also will be effected by lack of homogeneity in the sample under test, for the flame plays on only a few square millimetres of fabric. If the pilot flame was left in the forward position against the sample for the duration of the test it would hardly affect the performance of the more flammable materials, yet would give the others a chance to burn up. In practice a fabric is likely to be ignited by sources considerably larger than the pilot flame used in this test.

The time taken for the specimen to burn up to the top depends partly on the time that elapses before the flame penetrates through the material to the underside, when this happens the specimen burns up both sides at a faster rate. For the 60/40 wool-cotton mixtures it was found that half the specimens burnt up on the top side only, i.e. the flame did not penetrate the fabric. The other specimens were penetrated after a few seconds and then burnt up on both sides, the times for the latter were much shorter.

A similar behaviour was observed with cellulose nitrate film, exposed and processed. It failed the test if the emsulsion coated side faced the pilot flame, but if the other side faced the pilot flame there was a delay of some seconds before the flame penetrated the film, which then passed the test. This difficulty could probably be avoided if all specimens were ignited at the bottom edge. The time for flame penetration in this test was fairly repeatable for some materials but not for others, and it may be affected by local variations in the weave of the fabric and the fibres themselves.

The burning of materials which give only a small flame may be insufficient to readily burn the cotton thread controlling the end part of the test. This was observed with the natural silks.

4.4. Conclusions

It appears that all except the most hazardous materials pass the standard at present associated with the American Test, i.e. those which fall below Class V on the semicircular frame test. The two tests give, in general similar results and would appear to be measuring assentially the same physical properties of fabrics. There are, however, certain fabrics which give anomalous results with the American Test, though for some materials e.g. muslin, the result is better than that for the semicircular test.

References

(1) Flammability of Clothing Textiles. United States Commercial Standard CS 191-53.

(2) Lawson, D. I., Webster, C. T., Gregsten, M. J. The Flammability of Fabrics. F.R. Note No. 107/1954.

(3) Webster, C. T. The Flammability of Fabrics. Part II - in preparation.

Table 1

Results of tests

Material	Weight per unit area mgm cm^{-2}	Distance and time of spread on Semi-Circular Frame Test cm and seconds: Distance (cm)	Time (sec)	Classification on Semi-Circular test	Vertical Flame Speed calculated from Semi-Circular Frame Test cm/sec	Vertical Flame Speed measured by Torsion Balance apparatus cm/sec	Time taken on American Test (sec): Oven-Dried	Conditioned	Calculated vertical flame speed for conditioned specimens with American Test
Natural Silk A	1·35	15·2	4·2	II	16·7	11·5	3·5	3·9	24·6
Natural Silk B	1·38	17·1	6·0	II	15·0	9·2	4·0	3·8	25·2
Rayon Net	1·85	53·5(21 in)	48·0	below V	31·0	32·0	2·8	3·8	25·2
Rayon	2·95	"	73	below V	19·7	8·5	3·6	5·0	19·2
Muslin	3·43	"	54	below V	27·0	15·0	3·0	4·6	20·8
Newsprint	5·62	"	91	V	15·9	14·3	6·0	7·1	13·5
Chart Paper	5·93	"	80	below V	18·0	17·0	5·0	4·6	20·8
Cotton A	6·44	"	106	V	13·7	9·42	5·7	6·6	14·5
Cotton B	8·10	"	137	V	10·4	8·7	7·0	7·4	12·9
Thin Brown Paper	8·80	"	127	V	11·3	10·8	6·5	7·6	12·6
Misson	6·48	"	151	IV	9·5	12·2	5·4	8·1	11·8
Gingham	9·48	"	158	IV	9·0	7·0	8·6	9·9	9·7
Rayon	9·97	"	205	IV	6·8	5·2	9·0	12·0	8·0
Wool Cotton 60/40	12·50	30·5	72	III	5·6	5·9	25	45	3·8
Cotton C	12·50	53·5(21 in)	201	IV	7·0	6·40	12·0	13·2	7·2
Winceyette A	13·30	"	194	IV	7·2	5·0	13·3	13·8	7·0
Winceyette B	13·32	49·5	263	III	5·1	2·7	13·1	15·7	6·1
Cartridge Paper	13·66	46	153	III	7 2	6·6	13·3	22·3	4·3
Wool Cotton Mixture 20/80	13·83	53·5(21 in)	277	III	5·0	5·4	30	27	3·6
Thick Brown Paper	14·95	"	230	III	6·0	5·7	14·3	14·9	6·4
Cotton D	15·58	"	240	III	5·8	5·0	13·4	14·0	6·8
Lambspun Rayon	16·08	37·59	150	III	5·3	4·9	17·5	27·0	3·6
Wool	19·00	26·5	55	III	5·2	3·0	20	26·0	3·7
Nitrate Film Exposed and Developed	Emulsion uppermost							3·5	
	" downwards				271·4	210·4		11·6	27·1

All results for tests other than the oven-dried specimens in American Test are for specimens conditioned at 22°C and 57 per cent humidity.

APPENDIX

Relation between Semi-circular Test and American Test

In equation (1) D/T is the mean velocity of spread up to the point D.

Hence equation (1) becomes

$$V = 0\cdot078\ D^{3/2}\ \overline{V} \qquad \ldots\ldots (1A)$$

where $\overline{V} = D/T$.

Since this is valid for a variety of materials spreading different distances around the semi-circle it follows that the variation of the velocity V_x at a point "x" on the semi-circle is the same for different materials. A convenient equation to assume for this variation is

$$V_x = \frac{A}{x^n} \qquad \ldots\ldots (2A)$$

where A is a constant for any one material. The fact that this implies an infinite starting velocity can be disregarded as a small correction to the origin of "x" will meet this difficulty without making significant difference to the following argument. The equation also postulates a finite velocity just before the cessation of flame spread. This again is disregarded.

From equation (2A) we have

$$x^n \frac{dx}{dt} = A \qquad \ldots\ldots (3A)$$

i.e.

$$\frac{x}{t} \cdot \frac{x^n}{n+1} = A$$

Now x/t is the mean velocity of spread $\overline{V}_x$ up to the point "x" so that from (2A) and (3A)

$$\overline{V}_x = \frac{(n+1)A}{x^n} = (n+1)\ V_x \qquad \ldots\ldots (4A)$$

The above argument on the similarity of behaviour of different materials also implies that equation (1A) can be written

$$V_1 = 0\cdot078\ x^{3/2}\ \overline{V}_x \qquad \ldots\ldots (5A)$$

Equation (2A) is therefore satisfied if $n = 3/2$. Hence from (4A) and (5A)

$$V_x = \frac{\frac{2}{5} V}{0\cdot078\ x^{5/2}} \qquad \ldots\ldots (6A)$$

If x is put equal to 13·3 cm (5·25 in.) the distance round the semi-circle to reach a slope of 45° we get the local velocity at a point where the slope is 45° as

$$V_{45} = \frac{V}{9\cdot45}$$

If the distance of spread along the incline in the American Test is taken as 10 cm (4 in.) it follows that

$$V = \frac{96}{T_A} \qquad \ldots\ldots (7A)$$

Where T_A is the time of spread in the American Test.

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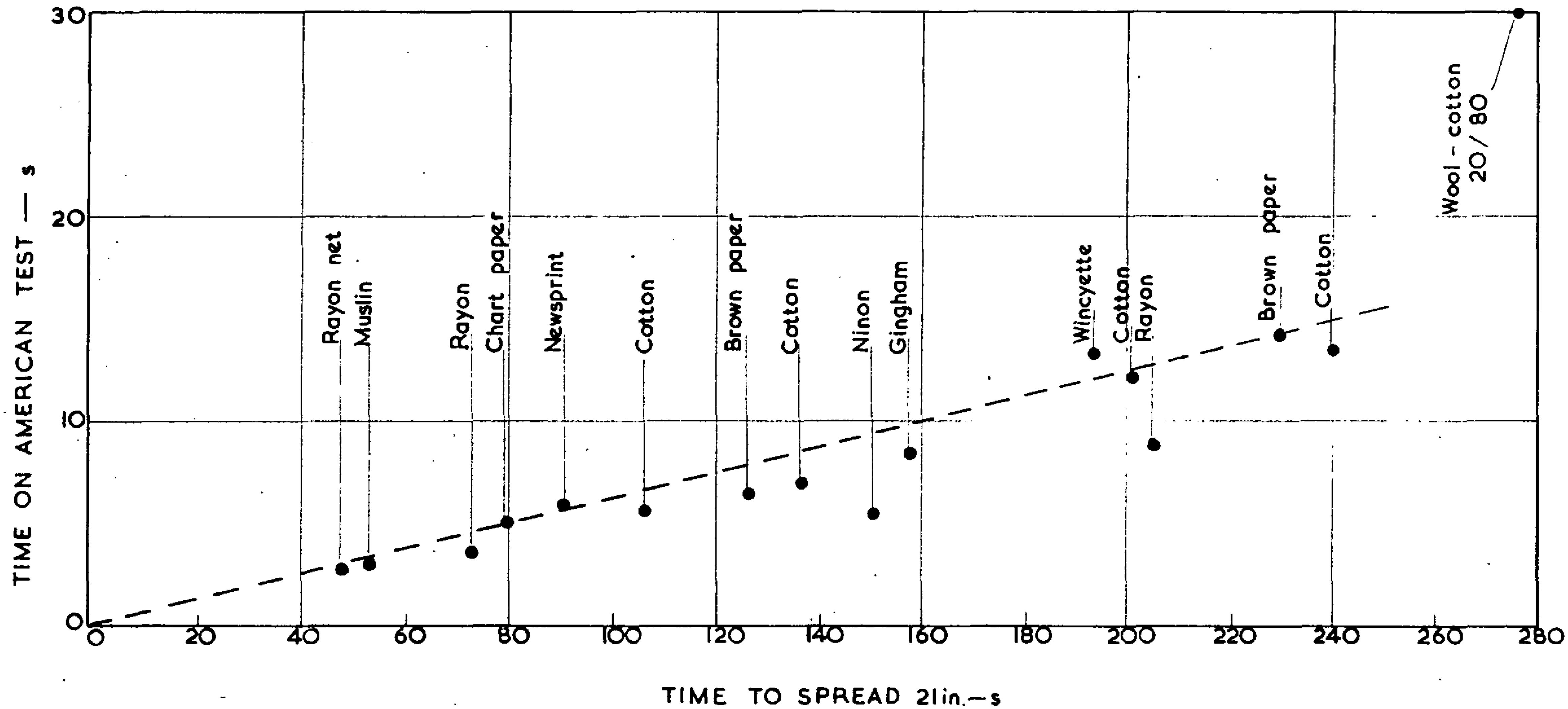

FIG.1. RELATION BETWEEN TIME TAKEN ON AMERICAN TEST AND TIME TO SPREAD 21 in. ON SEMICIRCULAR TEST

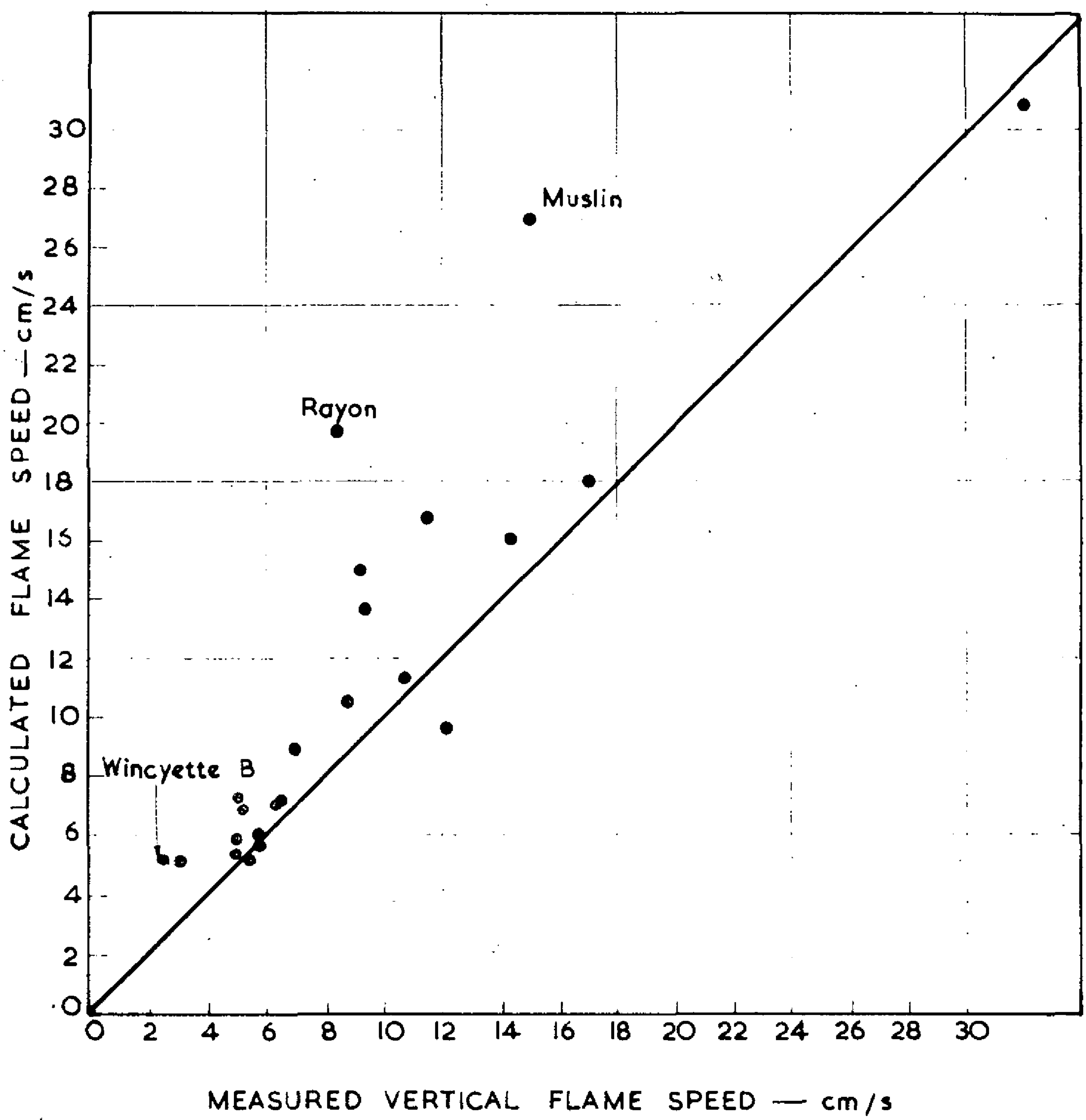

FIG. 2. CALCULATED & OBSERVED VERTICAL FLAME SPEED FROM SEMICIRCULAR TEST

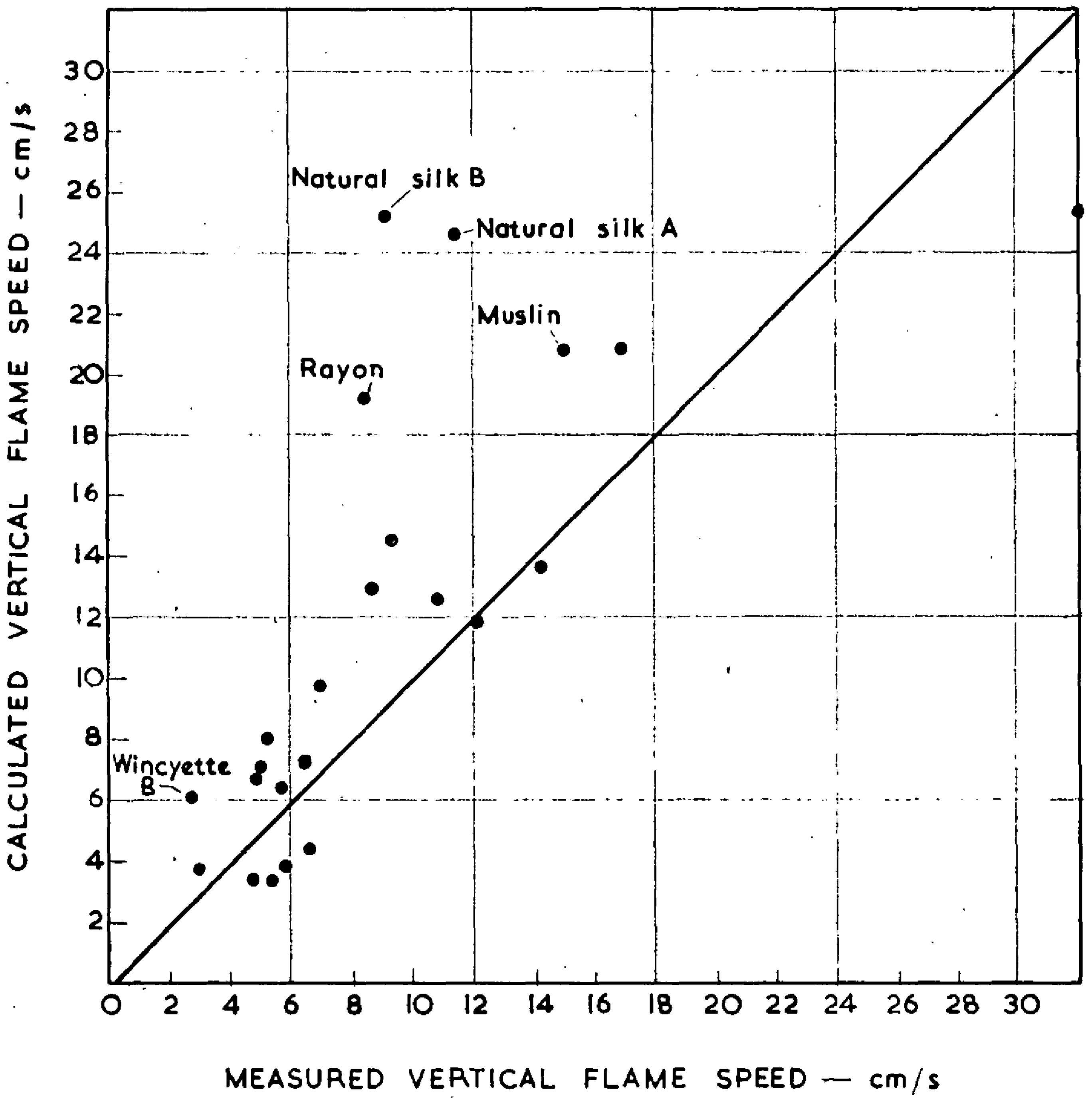

FIG.3. CALCULATED & OBSERVED VERTICAL FLAME SPEED FROM AMERICAN TEST

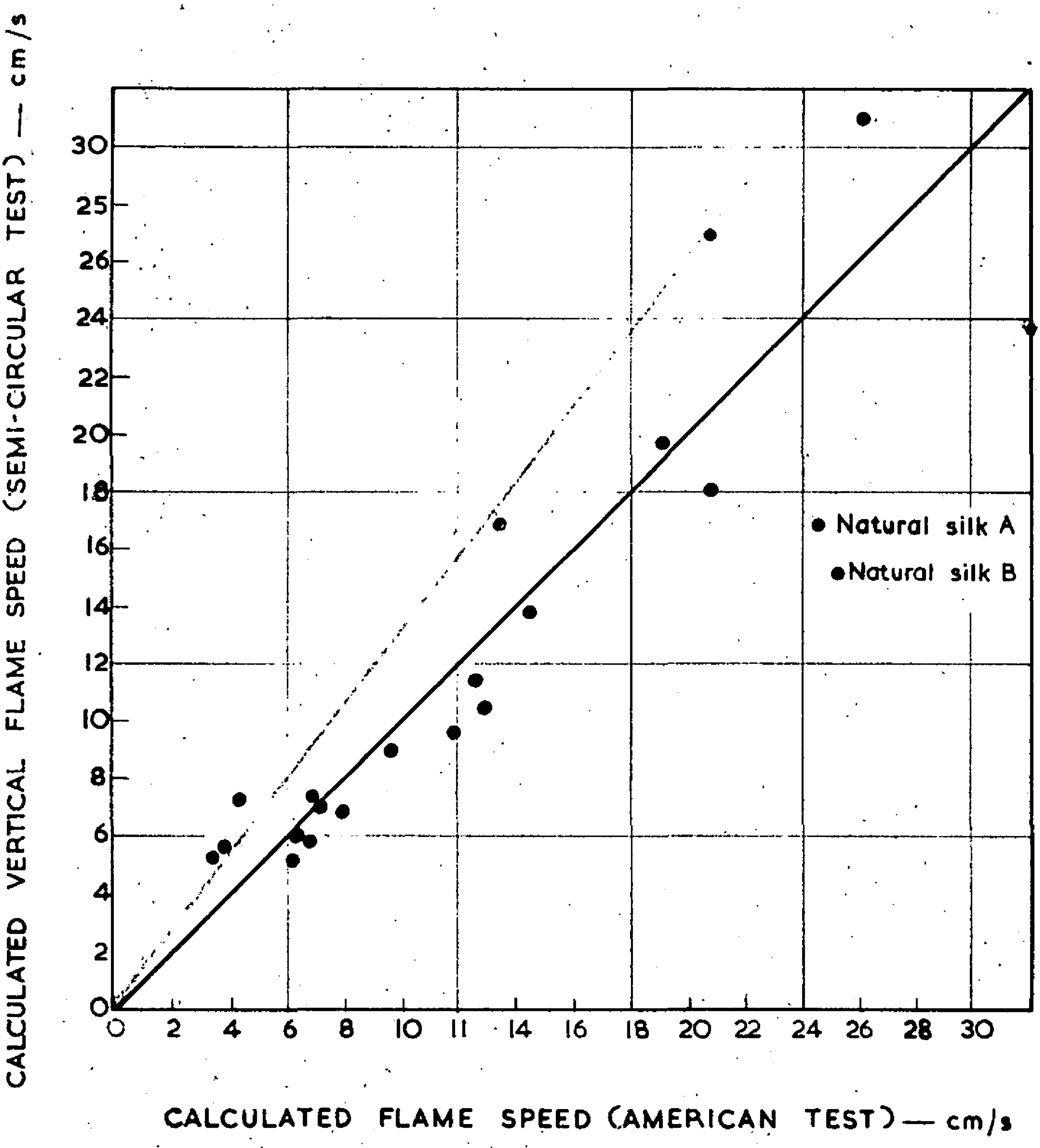

FIG.4. COMPARISON OF TWO TESTS

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