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THE FLAMMABILITY OF FABRICS -

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Summary

The measurement of the speed of propagation of flame over fabrics is discussed and some general relations between flame speed and the weight of the fabric per unit area are described. Methods are outlined for the measurement of vertical flame speed with simple robust apparatus. A survey is described by which it is hoped to examine the relation between the incidence and severity of burning accidents and the vertical flame speed of the materials involved.

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INTRODUCTION

Textiles are flexible woven materials. The spinning and weaving processes associated with their manufacture ensure that the finished materials are more or less a well aerated mass with good thermal insulating properties; unfortunately, this leads to conditions which are favourable to ignition and to the propagation of flame. Textiles, being flexible and subject to the usual gravitational forces, usually hang vertically; it is in this position that flame is most readily propagated and the heat transfer from the flame to the unburnt fabric ahead of the flame is greatest.

MEASUREMENT OF VERTICAL FLAME SPEED

In assessing the danger of any fabric, it will be necessary to measure the vertical flame speed, as this is a measure of the time available, either for extinguishing the flames or for discarding the burning fabric. As burning is a continuous process of ignition, any such measurement will also take into account the ease of ignition of fabrics.

It is not easy to measure vertical flame speed over fabrics directly as the flame front is not well defined. It is, however, possible to measure the vertical flame speed indirectly by weighing the fabric continuously on a torsion balance while it is burning [1]. The vertical flame speed is readily calculated from the rate of loss of weight, the initial weight of the fabric and the weight of the residue. The apparatus is shown in Figure 1, and some typical results are given in Tables 1, 2, 3, 4 and 5, relating respectively to cotton and viscose rayon, acetate rayon, wool, nylon and miscellaneous fabrics.

All cellulosic materials, wood, paper and textiles, propagate flame at a rate which is inversely proportional to their weight per unit area, as shown in Figure 2. In fact, a useful formula to have in mind for cotton and viscose rayon fabrics is:-

$$WV = 9.3$$

where W is the weight in oz/yd^2
and V is the vertical flame speed in in./s.

It may be shown, without much difficulty, that a relation of this kind might be expected on theoretical grounds.

The corresponding expressions for other fibres have been determined with less precision because up to the present it has not been possible to test such a wide range of materials as with cellulosic fabrics, but the following relations are put forward tentatively:-

$WV = 5$ (acetate rayon)
$WV = 8$ (wool/cotton mixtures containing up to 60 per cent wool).

These figures would indicate that wool/cotton mixtures are about as flammable as, while acetate rayons are markedly less flammable than, cotton and viscose rayons of comparable weight.

The lower flame speed of acetate rayons is due to the fact that they melt and drip during burning and as each burning drip falls the flame front is momentarily checked, some of the heat from combustion being removed.

The data for the burning of wool do not permit a weight-velocity relation to be estimated but the figures which are available are not inconsistent with the flame speed being 2-3 times less than that for comparable weights of cotton.

Fabrics comprising mixtures of fibres have a flammability intermediate between that of the two fibres and very often characteristic of the more flammable of the fibres. Pure nylon and Terylene do not propagate flame continuously in a vertical direction. Nylon nets stiffened with melamine resins however propagate flame with the same velocity as cotton nets.

SEMI-CIRCULAR TEST

The torsion balance apparatus is, of course, quite unsuitable for everyday use, and this has led to the development of simpler apparatus (Figure 3) consisting of a semi-circular arched track over which the fabric to be tested is stretched. The sample is lit at one end and the final distance of burning D is noted, together with the time taken T. From these two quantities the vertical flame speed V, as measured by the torsion balance, can be estimated from the expression, shown graphically in Figure 4 :-

$$V = \frac{0.31\ D^{2.5}}{T}$$

The correlation between the vertical flame speed calculated in this way, and with that measured using a torsion balance is shown in Figure 5.

The semi-circular apparatus is described in B.S. 476 : Part 2[2], in which a figure of merit, M, is assigned to the sample under test. This is the time taken for flame to propagate 100 in. vertically, and it is derived from the distance and time of burning by the expression:-

$$M = \frac{320\ T}{D^{2.5}}$$

which is shown graphically in Figure 6. Typical values for various materials are shown in Tables 1, 2, 3, 4 and 5.

THE 45° TEST

The speed of propagation along materials sloping at an angle of 45° has been adopted as a criterion of flammability in the United States. Experiments have been carried out at the Fire Research Station in this way and it has been found possible in some cases to correlate the speed of burning with the vertical flame speed and hence with the figure of merit. Some typical figures are shown in Tables 1, 2, 3, 4 and 5. These have been found by measuring the time T for the flame to spread a distance of 5 in. along the slope and substituting in the empirical expression :-

$$M = 2.5\ T$$

The method of ignition specified in the American Federal Test is such that not all materials which permit the propagation of flame at 45° are ignited by the standard source, and in the experimental results quoted in Tables 1, 2, 3, 4 and 5, the igniting source was allowed to play on the fabric considerably longer than in the American specification. For some of the less flammable materials propagation along a 45° slope does not take place but nevertheless they will burn in the vertical direction owing to the more efficient heat transfer from the flames to the material. This will mean that there is a maximum figure of merit which can be measured on the American type of apparatus; the value of this maximum is not at present known.

DISCUSSION OF SEMI-CIRCULAR AND 45° TESTS

It will be seen on reference to Table 1 that both the semi-circular and 45° tests give a fair measure of the figure of merit of fabrics as determined by the vertical flame speed.

Both tests give figures of merit for acetate rayon considerably lower than those calculated from the vertical flame speed. This is undoubtedly due to the fact that the better support given to the fabrics in these tests as compared with the vertical test considerably reduces the dripping of the burning material.

The factor is also generally present when the tests are applied to woollen fabrics.

Pure nylon and Terylene fabrics do not propagate flame in the vertical direction and therefore would have an infinite figure of merit as determined by the vertical flame speed. The 45° test would also give this value as flame would not be propagated along the 45° slope.

The semi-circular test gives a finite figure of merit of several hundred as this is measured by both the distance and time of spread and a certain limited amount of flaming does take place near to the igniting source.

The same remarks would apply to all fabrics which do not propagate flame vertically including those receiving a number of proprietary flame-retardant treatments. When such fabrics have been laundered many times they will propagate flame slowly in the vertical direction and it is very doubtful whether propagation would take place at an angle of 45°. Under these conditions the semi-circular test is probably a more accurate measure of the figure of merit as determined by the vertical flame speed.

BURNS IN RELATION TO THE FIGURE OF MERIT OF FABRICS

In order to obtain information on the relation between the figure of merit and burning accidents, the Ministry of Health has been asked if it would enlist the co-operation of the Burns Units of hospitals in Great Britain in supplying both information regarding the accident and a sample of the fabric first ignited. The questionnaire in use is shown in Figure 7. This is printed on the back of the envelope into which a sample of fabric is placed.

When the envelope is received at the Fire Research Station, the figure of merit of the fabric is measured and recorded. The information is then coded onto punched cards by the Statistical Section.

From this survey it is hoped to answer three main questions :-

(1) What is the distribution of the number of burning accidents in relation to the figure of merit of the fabrics first ignited ?

(2) Is there any correlation between the extent and severity of burns and the figure of merit of the fabric involved ?

(3) What would be the effect on the pattern of burning accidents of encouraging the use of garments having a figure of merit higher than those in use at present ?

From an examination of the fabrics received so far from hospitals and from the Fire Brigades, it has been possible to prepare a distribution diagram of the number of burning accidents with respect to the figure of merit of the materials first ignited. The distribution diagram is shown in Figure 8, where it will be seen that the bulk of the accidents involve fabrics having figures of merit in the range 25 - 65; this is in part due to the frequency with which such fabrics are worn. The more flammable fabrics are not responsible for the bulk of burning accidents, probably because they are not so frequently used or because such light-weight materials are usually worn in summer when fires are not generally required. Whatever the cause, the implication is clear, that it would be useless to prohibit only the most flammable fabrics as has been done in the United States.

TABLE 1 - FLAME SPREAD OVER COTTON AND VISCOSE RAYON

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
Viscose net	0.5	13	7.7	8	7
Viscose net	0.5	16	6.3	6	7
Viscose net	0.7	9.4	10.6	9	10
Cotton net	0.8	14	7.2	7	8
Cotton muslin	1.0	6.0	16	9	8
Cotton net	1.3	18	5.6	6	8
Viscose	1.8	6.1	16	20	-
Cotton	1.9	3.5	29	17	14
Viscose ninon	1.9	4.8	21	21	14
Cotton seersucker	2.3	3.2	31	21	-
Cotton	2.4	3.4	29	22	18
Cotton gingham	2.8	2.8	36	26	22
Viscose	3.0	2.9	35	37	-
Viscose	3.3	2.7	37	30	-
Cotton	3.6	2.5	40	33	30
Cotton poplin	3.8	2.4	42	36	-
Cotton, embossed	3.9	2.4	42	30	-
Cotton winceyette	3.9	2.0	50	31	33
Cotton winceyette	4.0	2.2	45	34	-
Cotton	4.1	1.7	59	33	45
Cotton	4.1	1.9	53	33	48
Cotton	4.3	2.8	36	32	-
Cotton flannelette	4.3	2.4	42	35	-
Cotton	4.6	2.0	50	38	34
Cotton, viscose	4.6	1.9	53	39	36
Viscose locknit	4.6	1.9	53	56	42
Viscose lambspun	4.8	1.9	53	56	44
Cotton cambric	5.6	1.8	56	46	-
Viscose, brushed	5.6	1.9	53	51	53
Viscose	5.6	1.6	63	67	-
Viscose, brushed	5.9	2.0	50	49	-
Cotton velveteen	6.3	1.9	53	50	-

TABLE 1 (cont'd) FLAME SPREAD OVER COTTON AND VISCOSE RAYON

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
Cotton furnishing fabric	7.3	1.4	71	60	-
Cotton velour	7.5	1.3	77	70	-
Viscose	8.1	1.1	91	80	-
Viscose, brushed	8.5	2.3	43	48	19
Cotton corduroy	8.9	1.4	71	65	-
Cotton loomstate weave	10.8	0.92	109	71	-
Cotton towelling	14.7	1.0	100	67	-

TABLE 2 - FLAME SPREAD OVER ACETATE RAYON

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
Acetate rayon	1.7	1.7	59	10	16
Acetate rayon	1.7	1.9	53	11	-
Acetate rayon	2.3	1.5	67	9	16
Acetate rayon	2.8	1.7	59	18	18
Acetate rayon lingerie	2.9	2.1	48	30	23
Acetate rayon lingerie	2.9	1.9	53	26	23
Acetate rayon lingerie	3.6	1.5	67	22	22
Acetate rayon lingerie	3.8	1.4	71	23	21
Acetate rayon satin	4.9	0.87	115	22	27
Acetate rayon twill	6.9	0.90	111	42	38

TABLE 3 - FLAME SPREAD OVER WOOL

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
Wool	3.7	0.69	145	47	-
Wool	3.9	0.81	124	47	-
Wool	5.6	0.69	145	49	-
Wool	7.5	0.31	323	136	-
Wool	7.8	0.68	147	159	-
Wool, knitted	8.1	0	∞	105	-
Wool serge	13.7	0	∞	over 200	-
Wool serge	18.6	0	∞	over 200	-

TABLE 4 - FLAME SPREAD OVER NYLON

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
Nylon net	0.4	3.3	30	8	-
Nylon net	0.4	-	-	8	-
Nylon net	0.4	2.7	37	8	-
Nylon	1.1	0	∞	over 200	-
Nylon	1.4	0	∞	over 200	-
Nylon	1.4	0	∞	over 200	-
Nylon	1.6	0	∞	over 200	-
Nylon	1.9	0	∞	over 200	-
Nylon	2.0	0	∞	over 200	-

TABLE 5 - FLAME SPREAD OVER MISCELLANEOUS FABRICS

Description	Weight per unit area oz/yd^2 W	Vertical flame speed in./s V	Figure of merit $M = \frac{100}{V}$	Figure of merit Semi-circular test	Figure of merit American test
20% wool 80% cotton	3.7	1.8	56	58	-
20% wool 80% cotton	4.0	2.1	48	44	76
40% wool 60% cotton	3.5	2.2	45	42	-
40% wool 60% cotton	4.4	2.0	50	46	-
50% wool 50% viscose	7.7	0.67	149	336	-
55% wool 45% cotton	3.9	2.0	50	51	-
60% wool 40% cotton	3.7	2.3	44	52	-
60% wool 40% cotton	4.1	1.7	59	71	-
50% wool 50% nylon	8.5	0	∞	194	-
50% wool 33% viscose 17% nylon	7.7	0.47	213	100	-
50% wool 33% nylon 17% viscose	8.6	0	∞	435	-
Linen crash	5.4	2.1	48	43	-
Winceyette: 50% Fibrocota 33⅓% viscose 16.2/5rds nylon	3.9	1.1	91	50	-
Wool-Orlon	6.4	1.1	91	120	-
Wool-polyacrylonitrile	8.7	0.8	125	90	-
Cotton, Erifon treated	5.9	0	∞	over 200	-
Cotton, Erifon treated	6.3	0	∞	over 200	-
Cotton, Erifon treated	8.5	0	∞	over 200	-
Canvas, Erifon treated	15.3	0	∞	over 200	-
Cotton, Proban treated	5.1	0	∞	over 200	-
Viscose, Proban treated	8.5	0	∞	over 200	-
Canvas, Proban treated	9.9	0	∞	over 200	-
Cotton twill, Proban treated	12.2	0	∞	over 200	-
67% viscose 33% Fibrolane	5.4	1.8	56	83	-
67% viscose 33% Fibrolane	5.6	1.6	63	88	-
67% viscose 33% Fibrolane	7.4	1.3	77	101	-
67% viscose 33% Fibrolane	9.1	1.4	71	99	-
Viscose -Orlon	8.7	1.8	56	68	-
Viscose - Terylene	9.0	1.0	100	80	-

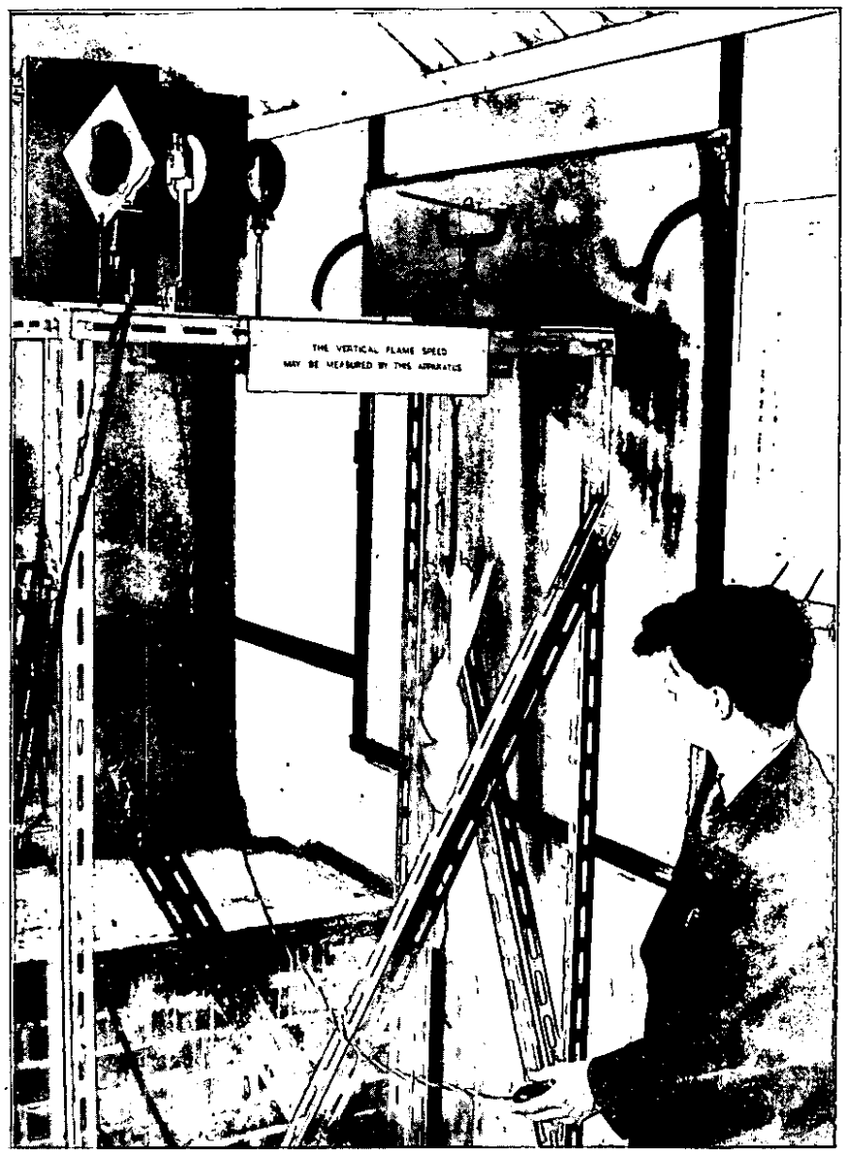


FIG.I. APPARATUS FOR MEASURING VERTICAL FLAME SPEED

FIG. 2. RELATIONSHIP BETWEEN VERTICAL FLAME SPEED(V) AND WT. PER UNIT AREA FOR CELLULOSE MATERIALS

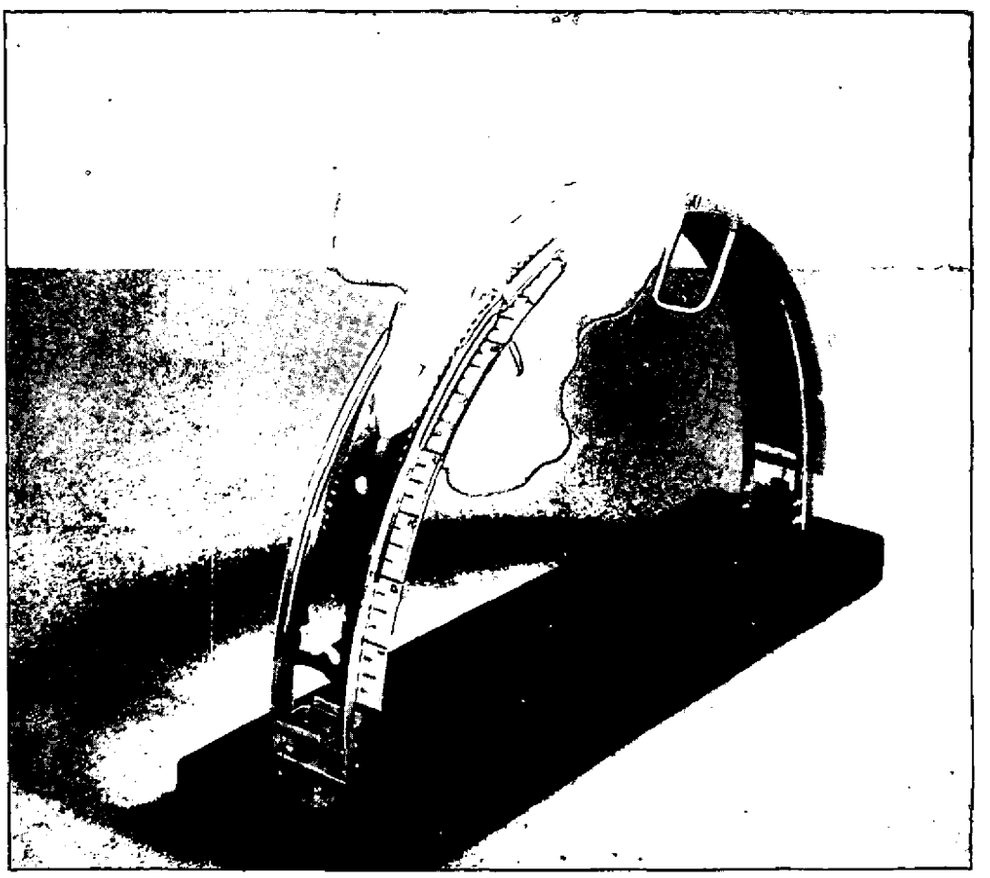
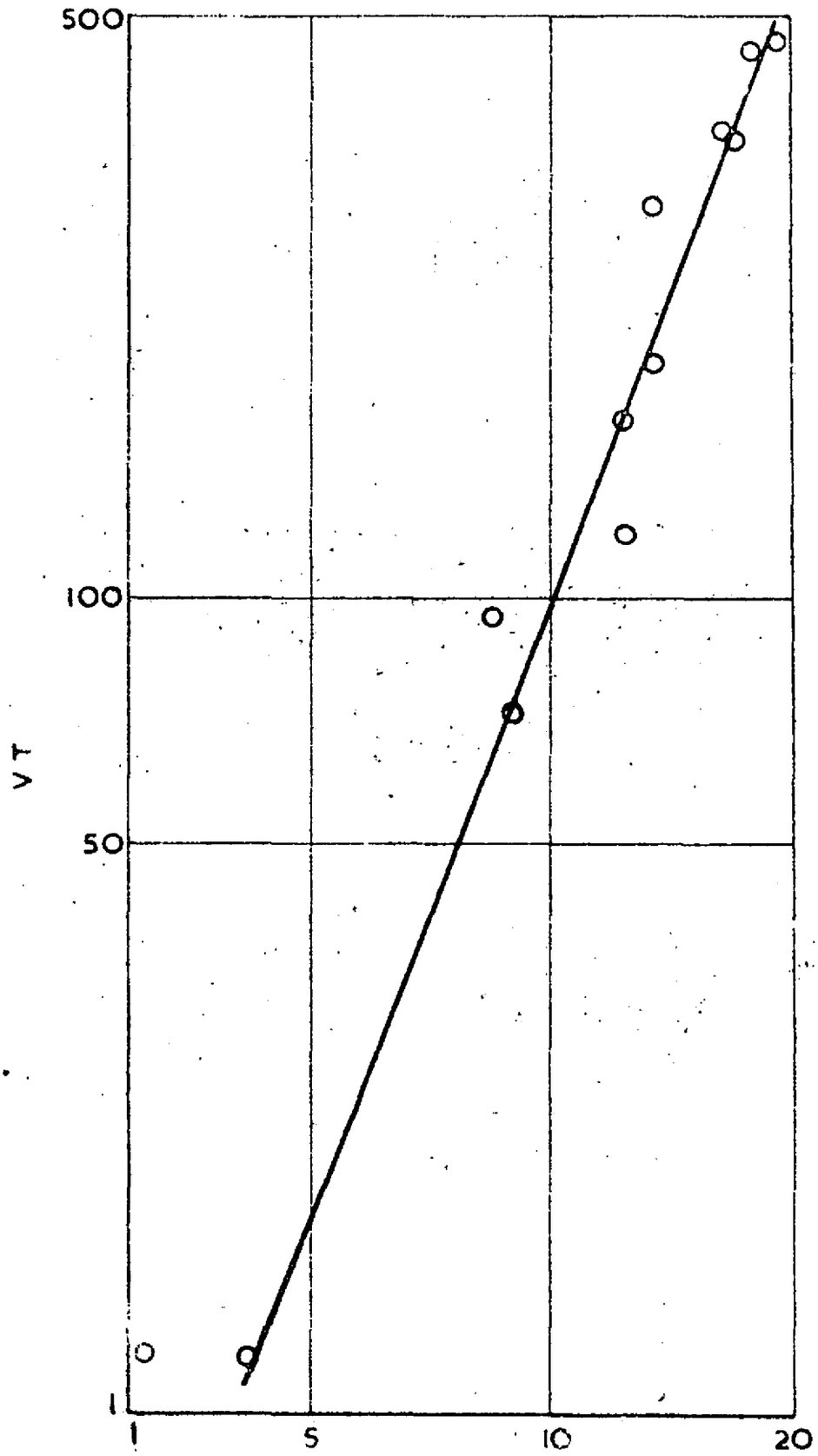


FIG. 3. SEMI-CIRCULAR APPARATUS FOR CLASSIFYING FABRICS



$VT = 0{\cdot}31D^{2{\cdot}5}$

V = vertical flame speed in in./s

T = time in sec to spread distance D in.

FIG. 4. ESTIMATION OF VERTICAL FLAME SPEED