F.R. Note No. 107/1954

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





# THE FLAMMABILITY OF FABRICS

by

D. I. Lawson, C. T. Webster and M. J. Gregsten

## Summary

Two methods of assessing the flammability of fabrics are described. In one the rate of burning of fabrics in the vertical direction is measured, and in the other, a more robust instrument suitable for general use, a strip of the material is clamped around a semicircular frame and the distance or time of spread of flame around the semicircle is observed.

April, 1954

File No. E/4/3(P)

Fire Research Station,
Boreham Wood,
Herts.

THE FLAMMABILITY OF FABRICS

by

D. I. Lawson, C. T. Webster and M. J. Gregsten

## Introduction

The fire hazard of flammable fabrics is well known, and there have been many attempts to devise tests by means of which fabrics can be graded according to their degree of flammability.

In this country a Non-Inflammability Test was introduced with B.S.476 in 1932. This test has been followed in several European countries, despite a growing conviction that it does not fully represent behaviour of materials under practical conditions, and that certain awkward discrepancies occur. During the revision of B.S.476 in 1953, it was considered that the Non-Inflammability Test should be omitted, and that consideration should be given to the development of an alternative that would be applicable to any materials in thin sheet form.

It is generally agreed that a fabric presents the greatest hazard when it is hung vertically, and it is therefore desirable that any test should give a reliable indication of the probable behaviour in this position. Flames travel so rapidly in the vertical direction, however, and the flame front is so badly defined that it is not easy to measure visually the rate of spread of flame accurately on a specimen of convenient size. Consequently, vertically held specimens are only used nowadays in assessing the efficiency of fire retardant treatments, or of fabrics in which vertical spread of flame is limited. Nevertheless, it was considered that the first step in a re-examination of this problem should be an attempt to find some means of measuring the rate of spread of flame on a specimen held vertically, and then, if possible, to develop a convenient form of test that would give results in agreement with practical observations. It was decided that one way of measuring the vertical flame speed would be to weigh the burning sample continuously. This would enable the rate of loss of weight to be calculated, and from it the vertical flame speed deduced.

## Apparatus

The sample under test was suspended on a torsion balance (fig.1) consisting of a steel wire 0.036 in. diameter and 7½ in. long tensioned between the arms of a U-shaped casting. The balance arm was fitted with an adjustable counter weight and a small concave mirror was fixed at the fulcrum. A parallel beam of light was directed at the mirror and focussed on photographic paper which was wrapped round a 7 in. diameter cylindrical drum in the camera. The camera drum was supported on a synchronous motor which rotated it at a speed of one revolution every 15 seconds. A continuous trace was left on the photographic paper as the drum rotated thus recording the movement of the mirror on the torsion wire. Before each sample was burned the apparatus was calibrated by hanging weights on the balance arm. A trace was obtained for each weight so that the photographic paper was subdivided by horizontal lines each corresponding to a particular weight. The sample was suspended on the balance arm and a trace obtained for its initial weight. It was then ignited at the lower end and a record of the loss of weight during burning was obtained. A typical trace is shown in fig.2. The oscillations on the trace are due to lack of damping of the torsion balance and the mean position of the trace is taken as indicative of the weight at any time. From the photographic record a graph is plotted of the weight of the sample as a function of time, and the flame speed is deduced as shown in fig.3. Before any systematic examination of different fabrics was commenced a number of samples each having different lengths was burned, and the maximum rate of flame spread calculated. Two typical examples are shown in fig.4 where it will be seen that the maximum rate of spread is not developed until a sample about 50 in. long is burned. In all subsequent tests the sample was 6 ft long by $1\frac{1}{2}$ in. wide.

## Materials

The list of materials tested is shown in Table I. It includes cotton, cotton treated with various concentrations of monammonium phosphate, materials made from various artificial fibres; wool and wool cotton mixtures, paper of various thicknesses and wood veneers.

TABLE I

Materials tested

| | | |
|---|---|---|
| Textiles | Wool serge | Wood veneers |
| Cotton (washed) | Nylon | Oak |
| Cotton (unwashed) | Terylene | Mahogany |
| Cotton soaked in Monammonium Phosphate Solutions | Wool cotton 20/80 | Walnut |
| | Wool cotton 40/60 | Teak |
| | Wool cotton 55/45 | Poplar |
| | Wincyette | Obeche |
| Concentrations:- | Flannelette | Iroko |
| 0·2% Soln | Net (dressed) | Ash |
| 0·4% " | Rayon (A) | Papers |
| 0.8% " | " (B) | Cartridge paper |
| 1·2% " | " (C) | Newsprint |
| 1·6% " | " (D) | Recorder chart |
| 2·0% " | " (E) | Brown paper |
| 2·5% " | " (F) | Miscellaneous |
| 4·5% " | Spun Rayon | Cinematograph Film |
| 8.0% " | Linen (crash) | (nitrate base) |

All the materials were first brought into equilibrium with an atmosphere at a temperature of 65°F and 60 per cent relative humidity. The impregnation of the cotton materials was carried out by immersing the sample in the impregnating solution which had been heated to 90°C. The solution and sample were then allowed to cool to room temperature. The sample was then dried in a horizontal position to prevent migration of the solution.

## Results

From the photographic trace the maximum rate of loss of weight could be found for each sample and this together with the calculated flame speed is shown in Table II.

It will be seen that the results for flame spread range from no vertical propagation to that of cellulose nitrate film which has a vertical flame speed of the order of 90 cm/sec. Wool, nylon and terylene were easily the least hazardous materials, though it may be that these results would be modified by the presence of dyes. A mixture of wool and cotton in the proportion of 45 per cent cotton to 55 per cent wool has almost the same flammability as plain cotton fabric. The fire retardant treatment of cotton using monammonium phosphate is only effective when solutions of a strength of about 8 per cent are used. Very low concentrations will actually increase the rate of flame spread.

## A simple apparatus for assessing flammability of fabrics

The apparatus described so far is only suitable for laboratory use and any commercial assessment of flammability would have to be made on much simpler and more robust equipment.

A measurement of the vertical flame speed cannot easily be made visually owing to the absence of a well defined flame front. An alternative method of assessing flammability is to allow the material to burn at various angles to the vertical and to see at which angle the sample is no longer able to support flaming. A simple way of doing this is to spread the sample over a semicircular track and having lit it at one end to note the distance to which the flame spreads.

The apparatus, shown in fig.5, has a diameter of 14 in. and the semicircular track is 21 in. long. The specimen is $1\frac{1}{2}$ in. wide and ignition is by the flame from 0·1 ml. absolute alcohol contained in a small trough 20 x 10 x 3 mm. It was found that a large number of materials burned completely round the semicircular track, but these materials can be differentiated from each other by noting the time taken to do this.

## Results

The distances or times of spread for the various specimens are recorded in Table II. In each case the mean result for three specimens is recorded. The distance of spread d round the semicircular track is shown graphically in relation to vertical flame speed V in fig.6, or for specimens burning completely round the semicircle, the time taken, T, to spread 21 in. is similarly shown in fig.7.

Empirical mathematical functions derived by fitting the best curves to the experimental points available give the following relationships:

$$V = 1.81\ d^{0\cdot4}$$

and $$V = \frac{1655}{T^{1\cdot03}}$$

The experimental observations from which the distance expression was derived have a standard percentage deviation of 17% from the curve defined by the expression, while the corresponding deviation for the second expression is 10·5%.

It will be seen that the vertical flame speed is roughly proportional to the square root of the distance of spread and inversely proportional to the time of spread for materials which burn completely round the semicircle.

In some instances standard deviations of the distances or times of spread of samples of a dozen upwards have been obtained. The most variable material tested so far has been a cellulose acetate film in which the mean distance of spread for 15 samples was 5·3 in. and the standard deviation was 2·9 in. The results for the other materials were considerably better, a typical material being a 40/60 wool/cotton mixture in which 15 samples gave a mean spread of 14 ins. with a standard deviation of 0·4 ins. For materials burning completely round the semicircle the times of burning were very consistent, a typical result being that for spun viscose rayon in which 15 samples gave a mean time of 197·6 seconds with a standard deviation of 5 seconds.

## Discussion

It will be seen from Table II that the weight of carbon residue of the treated cotton fabrics generally increases with the concentration of the ammonium phosphate solution. This might have been expected from a knowledge of Richardson's[1] results on the carbonization of wood after treatment with monammonium phosphate.

It may be assumed that the increase of carbon is at the expense of the volume of combustible gas given off. If the quantity of combustible gas burnt is less, then the heat transfer to the burning material is less and this should affect the speed of travel of the flame. Fig.8 does in fact show that vertical flame speed decreases as weight of carbon residue increases.

A further inspection of Table II reveals that the rate of loss of weight for the cellulosic materials (i.e. cottons (untreated), viscose rayon, papers and wood veneers) is fairly constant at around 0.30 grams/sec. This would be consistent with the fact that for such materials the weight/unit length largely determines the vertical speed of flame. In fig.9 the logarithm of vertical flame speed has been plotted against the logarithm of weight/unit area for these materials and suggests a linear relationship between these two quantities. It may therefore be said that for cellulosic materials the vertical flame speed is roughly inversely proportional to weight /unit area.

## Conclusions

An apparatus has been described whereby the upward speed of propagation of flame over a vertically hanging strip of material may be measured. It has been shown that this is proportional to the square root of the distance of burning of the material when supported round a semicircular track and that for materials burning round the semicircle the rate of vertical propagation is inversely proportional to the time of burning.

It appears from these tests that the vertical speed of burning of a wide variety of cellulose materials is inversely proportional to the weight per unit area of the materials.

## Bibliography

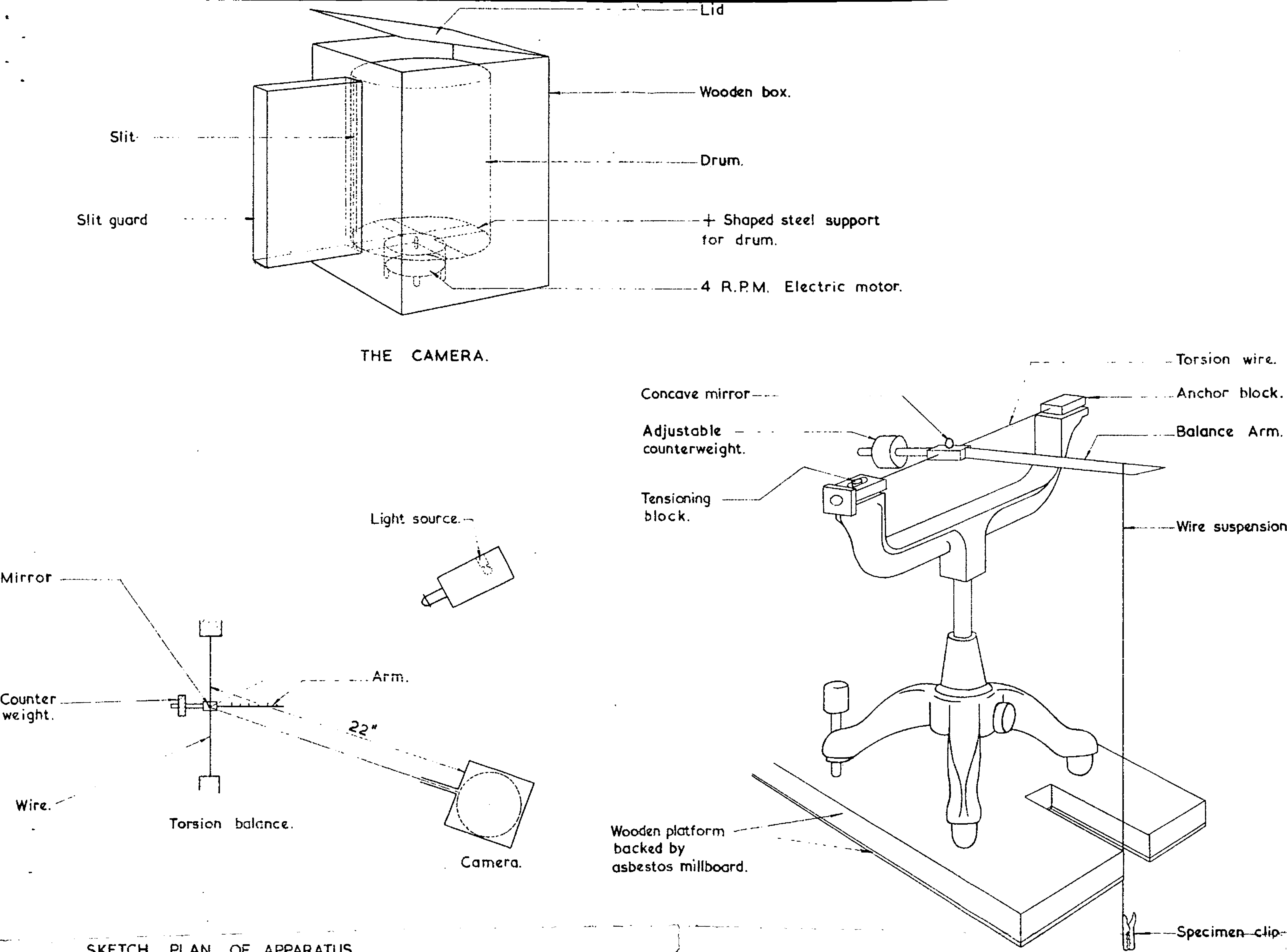
(1) Richardson, N. A. A new aspect of the action of timber fireproofing compounds. J. Soc. Chem Indus. Trans. Vol 56 p 202T 1937.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WOOL (serge) | 63.74 | | | No spread | | | |
| NYLON | 4.54 | | | No spread | | | |
| TERYLENE | 16.60 | | | No spread | | | |
| RAYON (A) | 22.78 | 0.25 | 12½ | 3.2 | 7 | | |
| RAYON (B) | 28.85 | 0.27 | 21 | 3.3 | 6¼ | | |
| RAYON (C) | 25.94 | 0.27 | 16½ | 3.3 | 5¾ | | |
| COTTON soaked in 8% soln. $NH_4H_2PO_4$ (Salt taken up 6.8% w/w) | 17.50 | 0.12 | 40 | 4.1 | 3½ | | |
| RAYON (D) | 31.61 | 0.36 | 16½ | 3.6 | 12½ | 141 | |
| WINCYETTE | 19.93 | 0.28 | 3 | 3.9 | | 72 | 328 |
| RAYON (E) | 19.00 | 0.26 | 13½ | 4.2 | 10½ | | |
| RAYON (F) | 18.56 | 0.28 | 14½ | 4.7 | 15⅓ | 68 | |
| COTTON soaked in 4.5% soln. $NH_4H_2PO_4$ (Salt taken up 4.05% w/w) | 17.10 | 0.15 | 39 | 4.4 | 9²/3 | | |
| WOOL COTTON MIXTURE 55/45 | 13.26 | 0.22 | 11 | 5.0 | 11¾ | | |
| UNWASHED COTTON | 16.78 | 0.30 | 0 | 5.8 | | 56 | 245 |
| WASHED COTTON | 16.40 | 0.28 | 0 | 5.0 | | 52 | 256 |
| WOOL COTTON MIXTURE 40/60 | 15.08 | 0.26 | 9¾ | 5.1 | 10⅓ | | |
| WOOL COTTON MIXTURE 20/80 | 13.33 | 0.26 | 10 | 5.4 | | 48 | 277 |
| COTTON soaked in 3.5% soln. $NH_4H_2PO_4$ (Salt taken up 2.75% w/w) | 16.90 | 0.18 | 38 | 5.0 | 11¼ | | |
| LINEN (Crash) | 18.65 | 0.37 | 6½ | 5.4 | | 41 | 263 |

## TABLE 2 CONT.

## RESULTS OF TESTS

| MATERIAL and TREATMENT | Weight per unit area | Vertical strip tests results | | | Semicircular test results | | |
|---|---|---|---|---|---|---|---|
| | mgm cm$^{-2}$ | Rate of loss of weight g. sec$^{-1}$ | Percent weight of residue | Vertical flame speed cm. sec$^{-1}$ | Mean final distance of spread in. | Mean time to spread 12 in. sec. | Mean time to spread 21 in. sec. |
| COTTON soaked in 2.5% soln. $NH_4H_2PO_4$ (Salt taken up 2.2% w/w) | 16.80 | 0.21 | 25 | 5.4 | 12 | | |
| COTTON soaked in 2.0% soln. $NH_4H_2PO_4$ (Salt taken up 2.0% w/w) | 16.70 | 0.24 | 26 | 6.0 | 12⅓ | 48 | |
| COTTON soaked in 1.6% soln. $NH_4H_2PO_4$ (Salt taken up 1.74% w/w) | 16.70 | 0.27 | 20 | 6.0 | 15½ | 44 | |
| CARTRIDGE PAPER | 14.70 | 0.38 | 9 | 6.5 | 18 | 32 | |
| COTTON soaked in 1.2% soln. $NH_4H_2PO_4$ (Salt taken up 1.29% w/w) | 16.60 | 0.30 | 20 | 6.7 | 17¼ | 47 | |
| COTTON soaked in 0.8% soln. $NH_4H_2PO_4$ (Salt taken up 1.21% w/w) | 16.60 | 0.33 | 14 | 7.1 | | 38 | 232 |
| COTTON soaked in 0.4% soln. $NH_4H_2PO_4$ (Salt taken up 0.85% w/w) | 16.50 | 0.38 | 10 | 7.7 | | 34 | 215 |
| SPUN RAYON (Viscose) | 10.96 | 0.32 | 0 | 7.5 | | 35 | 184 |
| COTTON soaked in 0.2% soln. $NH_4H_2PO_4$ (Salt taken up 0.81% w/w) | 16.50 | 0.37 | 7 | 7.2 | | 38 | 214 |
| FLANNELETTE | 12.50 | 0.30 | 0 | 6.1 | | 38 | 200 |
| BROWN PAPER | 8.80 | 0.30 | 13½ | 10.8 | | 19 | 127 |
| NEWSPRINT | 5.80 | 0.30 | 0 | 14.3 | | 15 | 91 |
| CHART PAPER | 6.40 | 0.36 | 9½ | 17.4 | | 14 | 84 |
| NET (Dressed) | 2.20 | 0.26 | 0 | 31.7 | | 18 | 49 |
| CINEMATOGRAPH FILM (Nitrate base, exposed and processed) | 22.03 | 7.00 | 0 | 91.4 | | 16 | 50 |
| OAK VENEER - Thickness 21.5 x $10^{-3}$ in. | 37.77 | NOT | MEASURED | | 12¼ | 91 | |
| MAHAGONY VENEER - " " 24.5 x $10^{-3}$ in. | 37.19 | " " | " | " " | 14½ | 73 | |
| WALNUT VENEER - " " 22 x $10^{-3}$ in. | 27.15 | " " | " | " " | 15½ | 55 | |
| TEAK VENEER - " " 28.5 x $10^{-3}$ in. | 44.12 | " " | " | " " | 16¼ | 78 | |
| POPLAR VENEER - " " 80 x $10^{-3}$ in. | 68.13 | " " | " | " " | 13¼ | 118 | |
| OBECHE VENEER - " " 23 x $10^{-3}$ in. | 17.40 | 0.37 | 6¼ | 5.0 | 15 | 48 | |
| IROKO VENEER - " " 43 x $10^{-3}$ in. | 67.05 | NOT | MEASURED | | 12¼ | 156 | |
| ASH VENEER - " " 27.5 x $10^{-3}$ in. | 40.87 | " " | " | " " | 16 | 71 | |




THE CAMERA.

Torsion balance.

SKETCH PLAN OF APPARATUS.

THE TORSION BALANCE.

FIG. 1. APPARATUS FOR DETERMING VERTICAL FLAME SPEED.

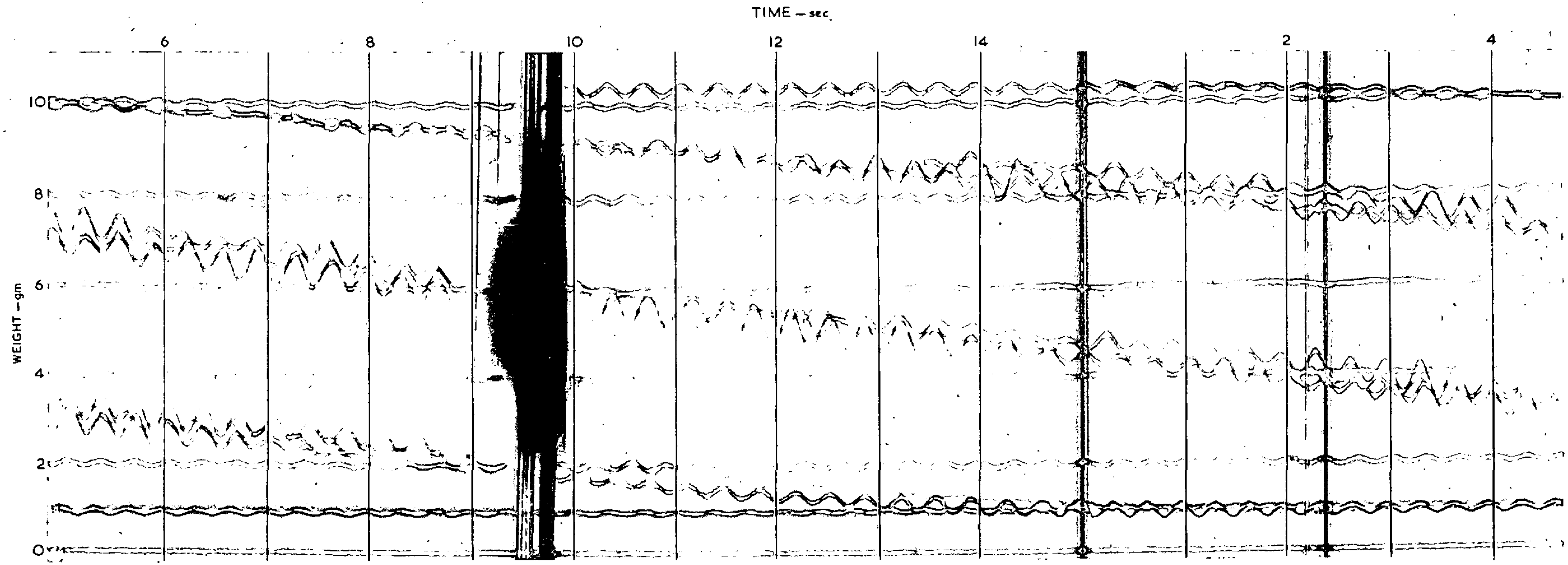
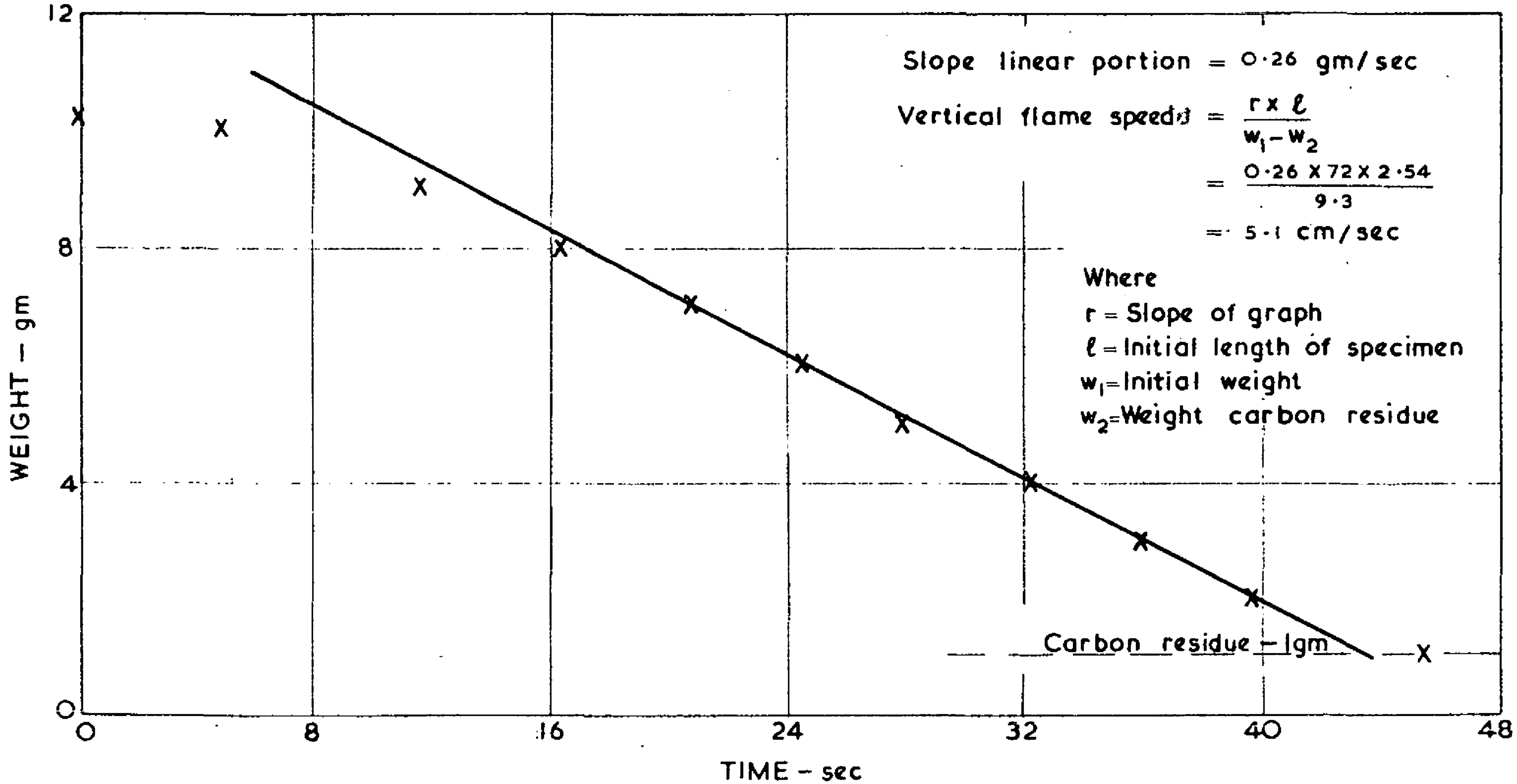



FIG. 2. TYPICAL PHOTOGRAPHIC RECORD — THREE SPECIMENS




40% WOOL / 60% COTTON MIXTURE

FIG.3. PLOT OF THE TYPICAL PHOTOGRAPHIC RECORD SHOWN IN FIG.2.

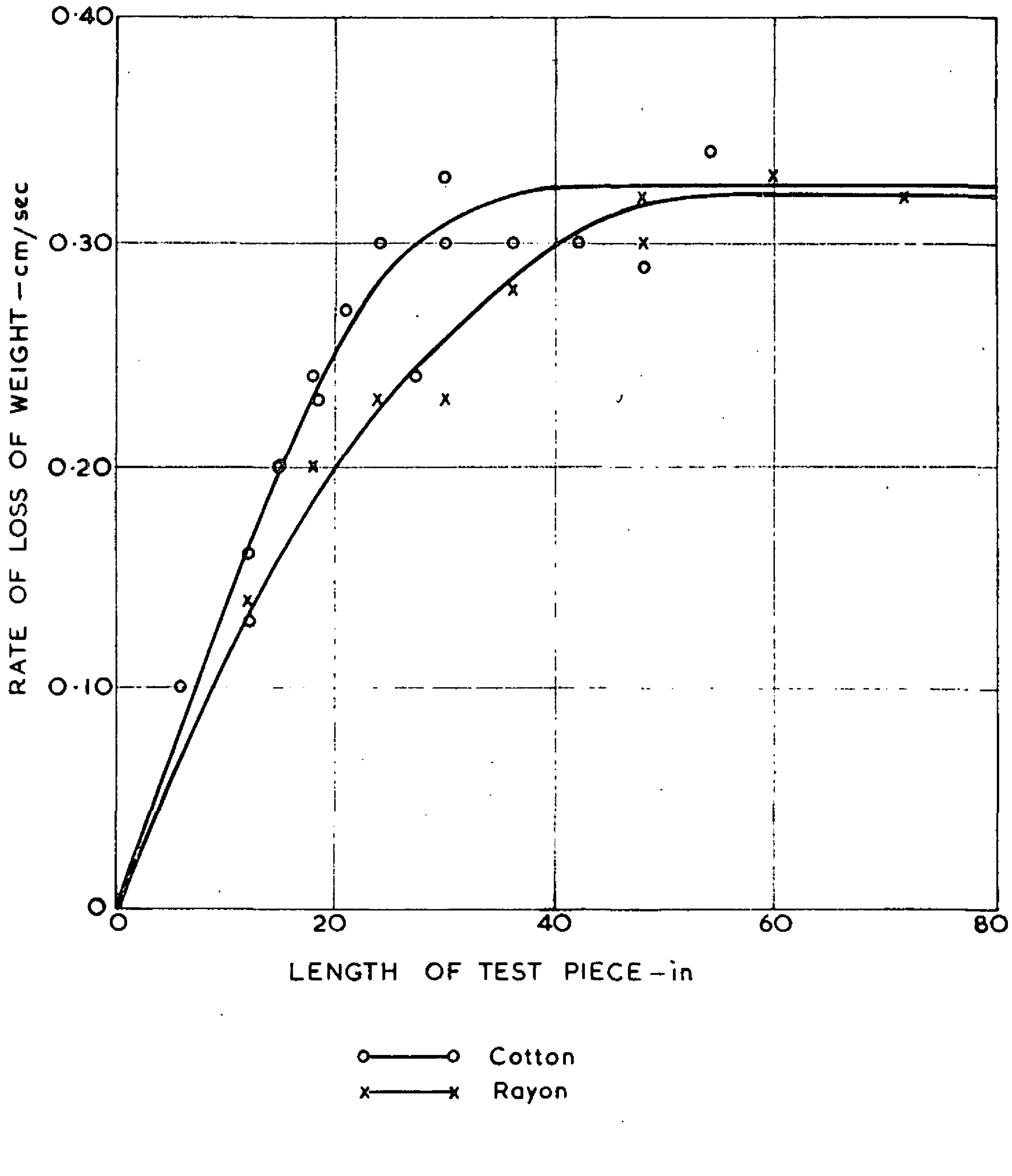



FIG. 4. THE MAXIMUM RATE OF LOSS OF WEIGHT BY BURNING OF A 1½" STRIP OF FABRIC

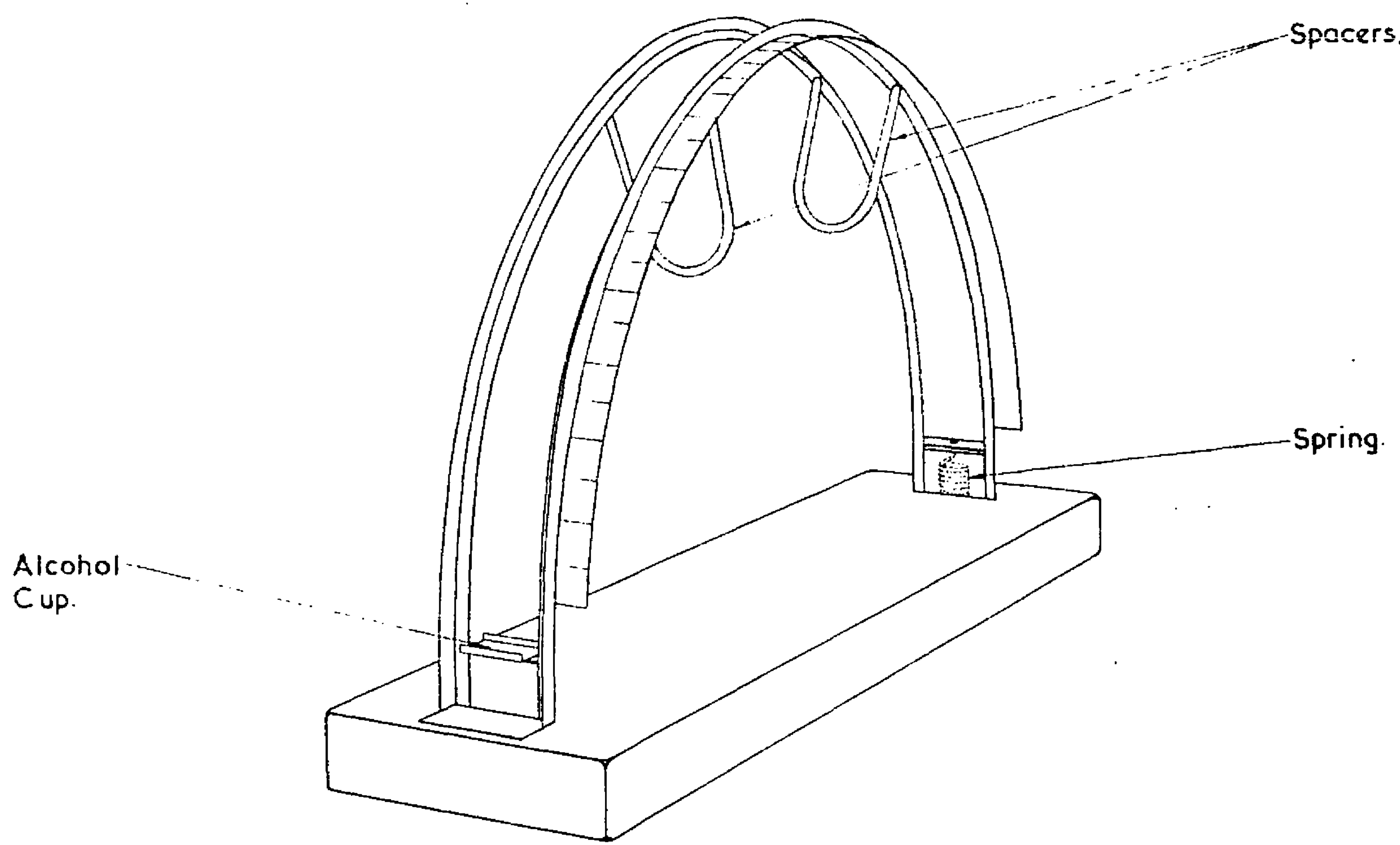



FIG. 5. APPARATUS FOR FLAMMABILITY TESTS ON FABRICS.

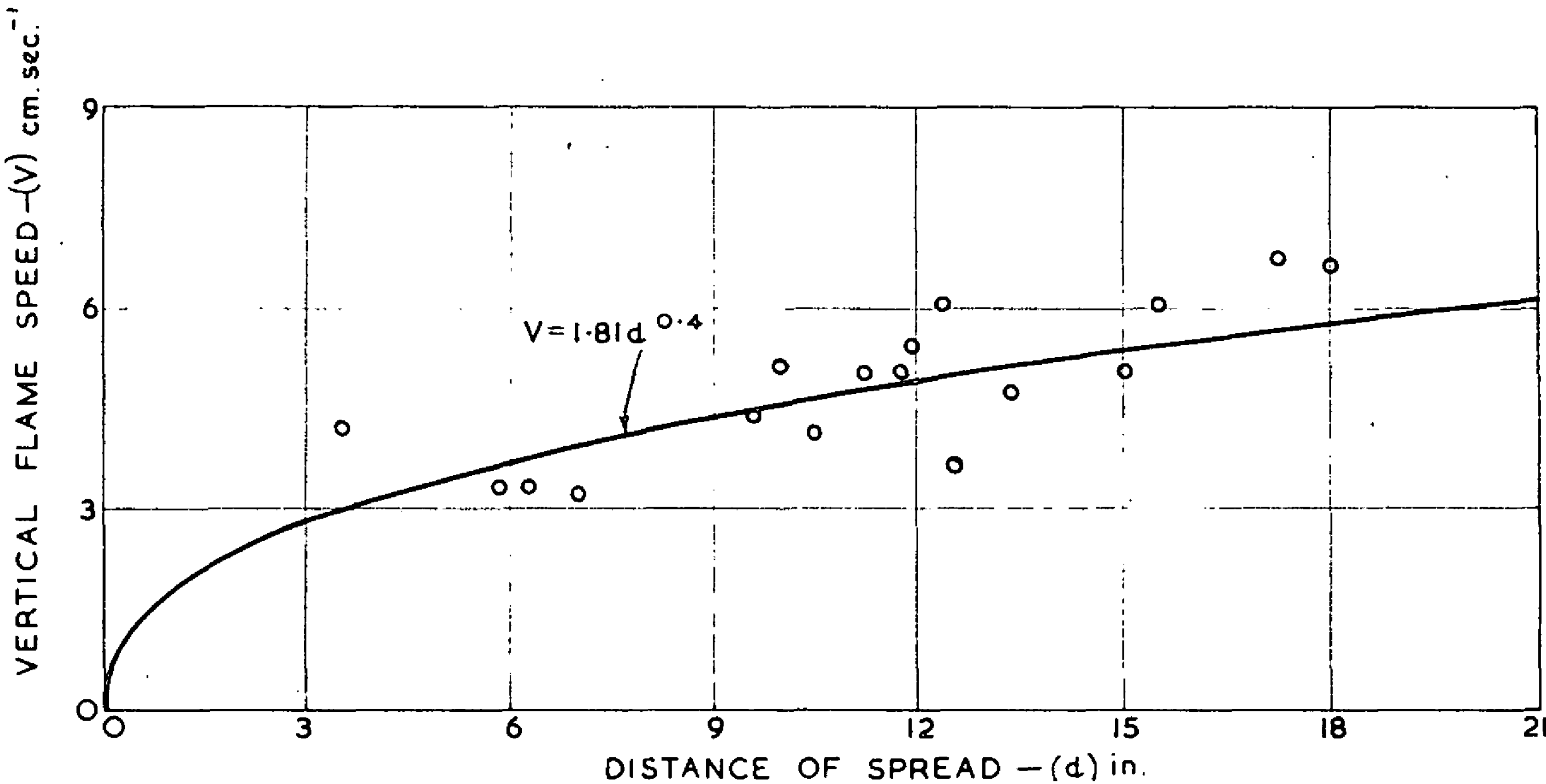



FIG. 6. RELATIONSHIP BETWEEN VERTICAL FLAME SPEED AND FINAL DISTANCE OF SPREAD ON SEMICIRCULAR TEST APPARATUS

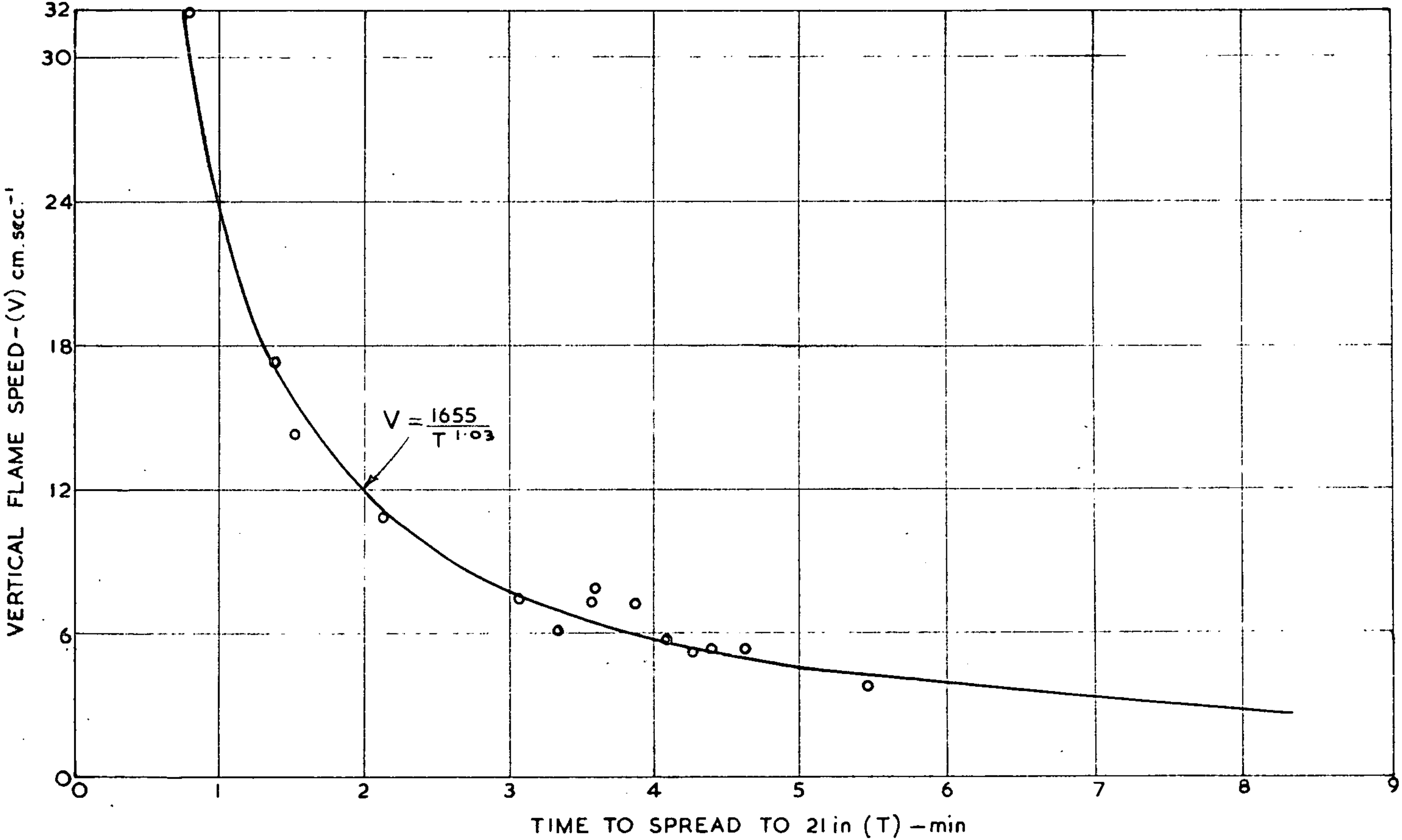



FIG. 7. RELATIONSHIP BETWEEN VERTICAL SPEED AND TIME TO SPREAD TO 21 in. ON THE SEMICIRCULAR APPARATUS.

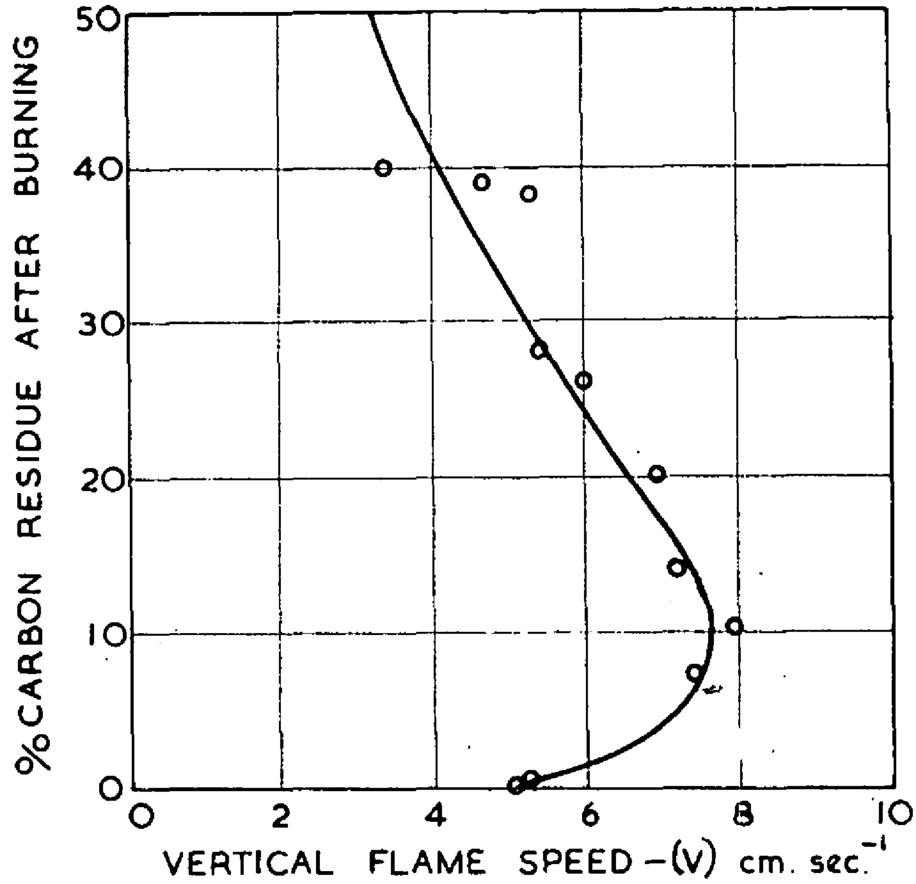



FIG. 8. CURVE SHOWING HOW VERTICAL FLAME SPEED IS A FUNCTION OF THE DEGREE OF CARBONISATION OF MONAMMONIUM PHOSPHATE TREATED COTTON AFTER BURNING

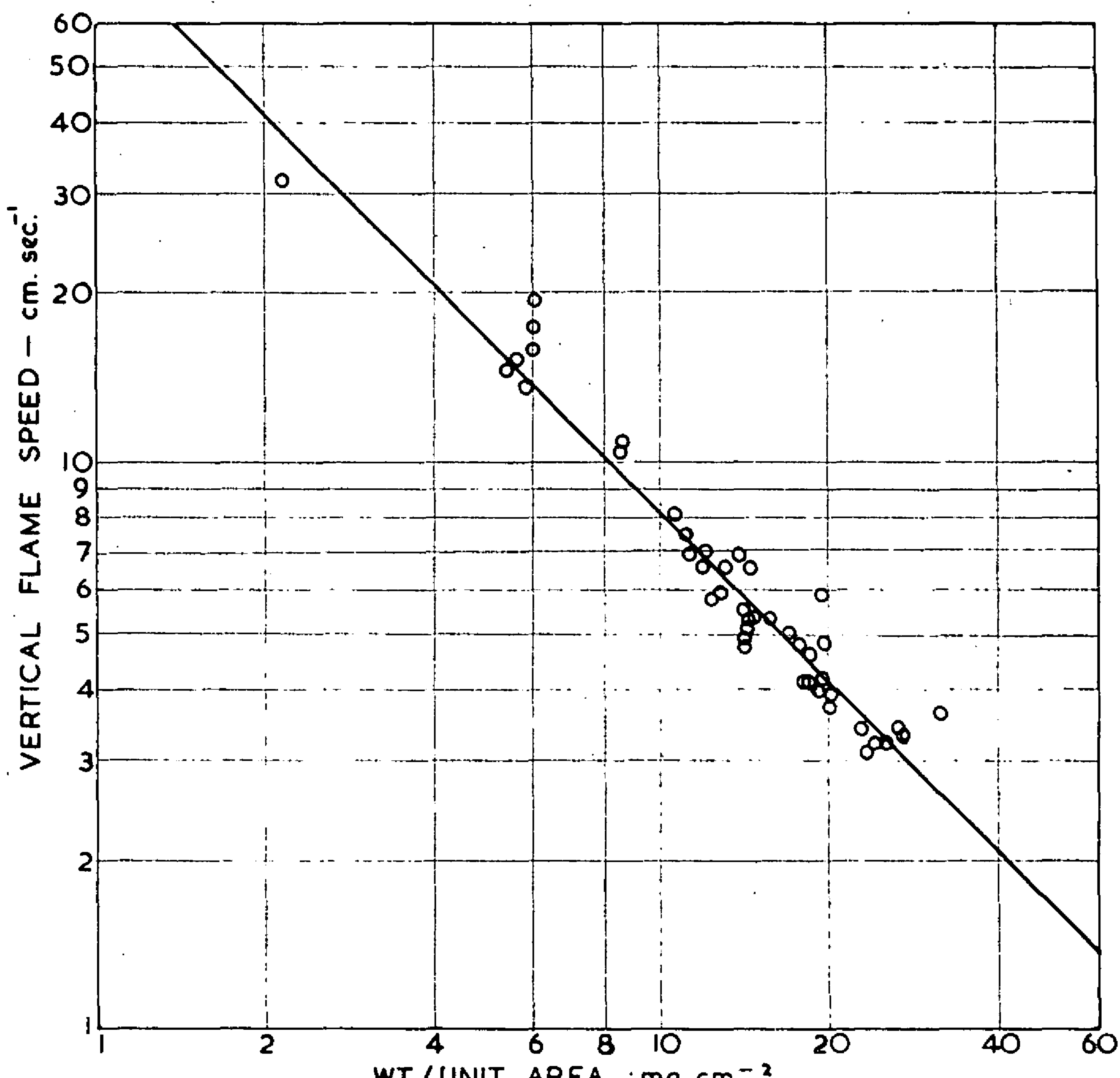



FIG. 9. RELATIONSHIP BETWEEN VERTICAL FLAME SPEED (V) AND WT. PER UNIT AREA FOR CELLULOSE MATERIALS