Flammability and Combustibility of Organic Foam Plastics

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20331540
Technical Translation (National Research Council of Canada), 1964

NATIONAL RESEARCH COUNCIL OF CANADA

Technical Translation 1140

Title: Flammability and combustibility of organic foam plastics (Entzündlichkeit und Brennbarkeit von organischen Schaumstoffen)

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Reference: Materialprüfung, 1 (9): 297-302, 1959

Translator: D.A. Sinclair, Translations Section, N.R.C. Library

FLAMMABILITY AND COMBUSTIBILITY OF ORGANIC FOAM PLASTICS

The combustibility of materials depends on many different factors. Reproducible and comparable test results can therefore be obtained only through carefully defined methods of investigation. Certain basic considerations enable us to determine the conditions for dimensioning the ignition source, for accurately determining the time of contact between the flame and the test specimen and for the elimination of disturbing influences. With the aid of the apparatus so developed the flammability and rates of flame propagation are determined for foam plastics, and by way of comparison for a number of non-foam materials as well.

The complex problem of the flammability and combustibility of materials can only be dealt with successfully when test methods are available that give reproducible results and which are based on accurate definitions. We shall first consider the underlying questions and then describe two apparatuses developed in the Bundesanstalt für Materialprüfung (Federal German Institute for Materials Testing) for determining the flammability and combustibility of foam plastics.

1. Development of the Methods of Investigation

1.1 Purposes of test for combustibility

The properties of long known and widely used materials of organic composition like wood, cork, leather, textiles, etc. are generally familiar from long experience and extensive research. In modern times, however the numbers of materials of natural origin have been greatly augmented by the products of the chemical industry which are known as plastics, of which we still have comparatively little experience.

The properties of these materials are being investigated from a great many different points of view.

Among the important properties of every material is its behaviour under thermal stress and especially its susceptibility to fire. This question is important in assessing its practical usefulness and its importance from the standpoint of safety engineering. The hitherto developed test methods which have proved effective and have been standardized, and which were to be published so as to make it possible to compare the results of investigations at various test centres, were often based on empirical methods determined by the orientation of the investigator. For instance, the external form of the material under investigation has to be taken into account, because the concepts of flammability, combustibility, etc. refer to the behaviour of a solid

undergoing a chemical reaction with a gas (oxygen or air). This heterogeneous reaction always takes place at the surface of the solid. A given material will behave differently, therefore, depending on whether it has the form of a compact body, a porous material, a hollow object, a foil, a powder or dust, a fabric or mesh, and so on. The shape and surface quality of materials must therefore be taken into account in the development and application of suitable methods of testing for flammability and combustibility. Thus susceptibility to fire cannot be expressed as a single generally applicable material constant like the specific weight, chemical composition and other such properties that are independent of the external form.

Along with the development of suitable methods of investigation for special fields of application, the results of systematic basic research must also be taken into account. These may help to forestall the application of unsuitable test methods and keep us from drawing the wrong conculsions from results that may in themselves be quite correct.

Recently the range of application of the plastics has been broadened by the development of possibilities for the manufacture of the so-called foam plastics. The use of these organic foam materials not only for everyday purposes (upholstery, etc.) but also in the construction industry (acoustic and heat insulation) makes it necessary to develop proper testing methods. Comparatively little is known as yet especially concerning the combustibility, among other properties, of these materials. The considerable increase of surface area due to their porosity, however, allows us to assume that they will be relatively more susceptible to fire and makes it imperative to investigate their combustion behaviour carefully.

The investigations of the thermal behaviour of foam plastics described below were carried out in the Federal Institute for Materials Testing in cooperation with the Rubber and Rubber Products Laboratory and the Combustible and Autoxidizable Materials Laboratory. Their purpose is the development and eventual standariization of apparatuses and methods with which the flammability and rate of flame propagation of foam plastics can be measured on a laboratory scale, i.e. on comparatively small specimens. In order to know the behaviour of larger quantities of foam plastics under intensified conditions, e.g. in a large fire, suitable tests would have to be conducted, taking into account, among other things, the amount of heat radiated. These problems, which are not considered in the present investigation, are of special importance from the standpoint of fireproofing in construction and fire protection as a whole.

1.2 Determination of flammability

The flammability of a foam plastic was defined as its capacity to burn with a flame when exposed to an ignition source without additional access of heat.

As a measure of the flammability we chose the time required to inflame a foam plastic specimen of given dimensions by exposing it to a given ignition source - in this case a flame of illuminating gas.

1.21 Time control of gas supply to the burner

In the first tests of this type the supply of gas to the burner was controlled by an electric photo-time switch and an electric valve. With this method however no reproducible results could be obtained, especially with materials that were easily ignited.

1.22 Flame pendulum method

In further testing a flame pendulum of the type commonly used in explosives laboratories for determining the flammability of nitrocellulose and propellant powders was employed. This apparatus is based on the following principle: a specimen mounted on a pendulum is made to swing through a flame of given size; the number of swings of the pendulum required to inflame the specimen is recorded. In the tests with foam plastics the apparatus was modified so that the period of the pendulum could be varied over a wide range by means of counterweights, up to the point, if possible, where inflammation would begin on only a single swing. The tests with this apparatus showed, however, that the maximum attainable time of contact between the flame and the specimen, which was 0.35 sec, led to ignition of the foam plastic in only a few cases. This was due to the fact that the motion of the specimen produced a turbulent flow of air that counteracted ignition or extinguished the flame in the event that an ignition took place. For this reason the tests with the flame pendulum were also abandoned.

1.23 Disc method

The difficulties that arose in the application of the flame pendulum could be avoided with an apparatus designed so that both the burner and the foam plastic specimen remain stationary. A disc with sectors cut out of it revolves between the burner nozzle and the specimen and makes it possible to limit the action of the ignition flame on the foam plastic specimen to variable, exactly measurable intervals of time. This test arrangement is represented in Fig. 1 and 2. The circular sector-shaped brass plates are joined together to form a disc a in such a way that after being mounted on

the shaft of a synchronous motor b, sector-shaped segments of various sizes can be left open. During rotation of the disc these openings permit access of the ignition flame from burner c to specimen d on holder 3 for a certain time, depending on the size of the segment. The rpm of the motor is exactly 60; if a 90° sector is left open, therefore, the specimen will be exposed to the flame for 0.25 sec. The exposure times can be varied by varying the size of the sector. A second revolution of the disc, and hence a second exposure to the flame, is prevented by stop pin f which drops into the open sector after one revolution.

The burner nozzle has a diameter of 0.5 mm. The length of the gas flame is kept to 40 mm by throttling the pressure. A pilot flame 2 mm high alongside the burner permits rapid extinction and relighting of the burner. The nozzle is 25 mm from the rotating disc. The 10 x 10 x 35 mm prismatic specimen of foam plastic is secured by steel prongs in a holder so that its bottom face is 40 cm from the nozzle tip of the burner. In testing, the at first small aperture angle of the open sector is increased until at least 8 out of 10 tests result in ignition of the specimen during the first turn of the disc. The test results are reproducible.

In the course of the investigations it was found advisable to put the whole apparatus in a combustion box DIN 53,906 and to have an apparatus for measuring and maintaining constant gas pressure outside the box (Fig. 3).

1.3 Determination of rate of flame propagation

In assessing the combustion properties of a material it is important to know the rate at which the flame spreads over the material as well as the flammability. An apparatus developed for this purpose permits direct measurement of the flame propagation time, i.e. the time (in sec) it takes the flame to travel from the ignited end to the other end of the specimen. The rate of flame propagation is obtained by dividing the length of the specimen by the flame propagation time. Finally, the proportion of the specimen burned can be stated (in percent by volume).

The first test setup developed for this purpose comprised a 50 x 300 mm galvanized iron wire screen bent at right angles in the centre between the long sides to form a trough, clamped in a support and tilted at an angle of 30° away from the horizontal. The specimen rested in the trough in such a way that its lower end projected 10 mm over the edge. The ignition source was a flame of illuminating gas of the type described above.

It was found that when the specimens are burned by this method a considerable quantity of heat is conducted away by the numerous highly conductive, interconnected wires and is thus lost to the reacting system. The heating

up of the specimen necessary for the propagation of the fire is delayed. Moreover the supply of air at the points of contact between the wire screen and the specimen is poorer than at the exposed places. This method was therefore abandoned in favour of one in which only a small amount of metal comes into contact with the specimen.

The newly developed apparatus (Fig. 4) comprises a rectangular metal frame 200 mm long, one side of which is mounted on guide rails which form the short sides of the frame in such a way that it can be moved parallel to the other long side. Five interchangeable prongs about 30 mm in length are mounted along the inside of each of the long sides at approximately 33 mm intervals. On each side a sixth prong is inserted between the fourth and fifth ones to prevent premature dropping of the remainder of the specimen before the conclusion of the test. The 10 × 10 × 150 mm rod-shaped specimen a is held by the prongs, the tips of which can be brought to a distance of 4 mm from each other by bringing the long sides of the frame closer together. A burner b of the type described above is mounted at one end of one of the long sides of the frame. (A burner mounted underneath the specimen would soon have its operation impaired by burnt particles dropping on it.) The apparatus is represented in Fig. 5 and 6.

2. Execution and Results of Tests

2.1 Flammability

After careful removal of any press skin a specimen (35 mm × 10 mm × 10 mm) is placed on the fork-shaped holder 3 (Fig. 2). The test flame is then lit from the pilot flame and finally the disc is made to revolve once so that the flame comes once into contact with the specimen. If the specimen does not ignite after the first revolution of the disc, i.e. after the flame has penetrated once to the sample through the gap in the disc, the test is repeated with a new specimen and a somewhat larger sector. This is repeated again and again until inflammation of the individual specimens occurs after a single revolution of the disc. If the specimen still does not ignite after a single revolution of the disc even with the maximum angle of aperture, the test setup is modified by replacing the disc by a strip of sheet brass that rotates like the hand of a clock. The time to ignition was then calculated from the angle of rotation. Times of more than 2 sec were measured with the stop watch.

It did not appear to make any difference to the inflammability of foam plastics whether the test flame touched an edge or a face of the specimen. The non-foam materials tested for comparison, on the other hand, showed distinct differences in the ignition times depending on the point of attack of the flame.

In Table I the values are given for the flammability of the foam plastics investigated. Foam plastics of different chemical composition were tested as well as ones of identical composition which differed only in their specific weight, i.e. in the degree of foaming.

In comparing the individual values of the test series for the flammability of the foam plastics good agreement was found.

A number of other materials were investigated by the same method. The results of these investigations are presented in Table II.

The method can probably be applied to the determination of flammability of other materials by varying the effective time of application of the flame, e.g. by varying the rpm of the disc.

2.2 Rate of flame propagation

After removal of the press skin where necessary, the specimen is placed between the separated long sides of the frames. By closing these sides the specimen is pierced by the prongs and is thus held symmetrically in the frame. The frame is then secured to a stand by means of a peg mounted on one long side so that the shorter sides of the frame are horizontal.

Tests are carried out first with the long sides inclined at an angle of 45° and then in horizontal position.

The test flame is applied laterally at the end of the specimen and at right angles to it. The flame remains in contact with it for 10 seconds and is then extinguished. With one specimen inflammation is applied to the lower end, with the next one to the upper end, and finally it is applied to one end of a specimen in horizontal position. A dish of water below the frame (not shown in the picture) prevents further burning of pieces of the specimen that melt and drop, as this might affect the test results.

The maximum rate of propagation was observed when the inclined specimen was ignited at the lower end. A lower rate was obtained when the specimens were held horizontal. It increased again when the inclined specimen was ignited at the top because the molten and burning pieces tended to flow down the specimen and thereby favour the flame propagation. Table III gives the values for the rate of flame propagation of the foam plastics investigated.

The tests were again carried out in the DIN 53,906 combustion box. Illuminating gas continued to be used as the fuel for the ignition flame, since it had been determined by tests that no measurable differences in the flammability or flame propagation values obtained occurred as a result of using other gases. As already stated in the section on "Flammability", a number of other materials were investigated by the same method. The results are presented in Fig. 4.

Tests with dry test specimens and tests in the air-conditioned room did not give the same results. The direction of foaming had a considerable effect here on the flammability.

Literature

1. Mendrzyk, H. Brennbarkeit und Entflammbarkeit von Folien. Kunststoffe, 46 (10): 81-88, 1956.

2. Proposed tentative specifications and methods of test for flexible urethane foam. Prepared by the Flexible Urethane Foam Test Methods Subcommittee of the SPI (Society of the Plastics Industry) Cellular Plastics Division. Reprinted from Rubber Age, August 1956.

Table I

Flammability of foam plastics

Dimensions of specimens: 35 mm × 10 mm × 10 mm

No.	Test material	Weight per unit volume g/cm^3	Total no. of tests	No. of specimens ignited	Flammability sec	Remarks
1	Polyisourethane (hard)	0.035	26	23	0.40	
2	Polyisourethane (hard)	0.063	14	12	0.45	
3	Polyisourethane (hard)	0.100	11	10	1.10	
4	Polyisourethane (soft)	0.037	15	-	-	Melts
5	Polyisourethane (soft)	0.052	10	-	-	Melts
6	Foam polystyrene	0.020	14	12	0.25	
7	Foam polystyrene	0.030	14	11	0.50	
8	Foam polystyrene	0.050	15	13	3.2	
9	Foam rubber	0.100	10	9	0.30	
10	Foam rubber	0.130	10	8	0.40	
11	Foam rubber	0.136	3	3	0.65	
12	Foam rubber	0.186	4	4	0.80	
13	Urea formaldehyde resin	0.009	4	-	-	Melts
14	Urea formaldehyde resin	0.014	4	-	-	Melts

Table II

Flammability of non-foam materials

Dimensions of specimens: 35 × 10 mm
Thickness - see Table

No.	Test material	Thickness of specimen mm	Total no. of tests	No. of specimens ignited	Flammability on front edge sec	Flammability on bottom face sec	Remarks
A.	Plastics						
1	Polyamide foil	0.07	6	5	0.8	1.1	–
2	PVC foil (soft)	0.13	11	9	0.35	–	–
3	PVC foil (hard)	0.10	5	4	2.20	–	–
4	Acetobutyrate foil	0.03	3	–	–	–	Melts
5	Polycarbonate foil	0.05	5	4	1.80	–	–
6	Cellophane foil	0.03	4	4	0.40	–	–
7	Polyethylene foil	0.10	4	4	2.40	–	–
8	Aminoplast molded mass	2.00	4	4	20	–	Goes out immediately
9	Phenoplast molded mass	2.00	4	–	–	–	Chars
B.	Textiles						
10	Ticking material	0.23	10	9	2.7	2.7	–
11	Awning material	0.58	5	4	3.2	4.1	–
12	Woollen material (100%)	2.20	3	2	11.4	13.6	Goes out immediately
13	Woollen mixture (70%)	1.60	6	5	4.3	7.4	Goes out immediately
14	Serge lining material	0.14	6	5	0.45	0.6	–
15	Nylon	0.11	4	–	–	–	Melts
C.	Paper, wadding						
16	Filled paper	0.13	3	3	1.7	1.9	–
17	Newsprint	0.08	4	4	0.8	0.8	–
18	Wadding	–	9	9	0.02	0.02	–

Table III

Rate of propagation of flames on foam plastics
Dimensions of specimens: 150 mm × 10 mm × 10 mm

No.	Test material	Weight per unit volume	Ignition of specimens												Remarks
			45° angle								Horizontal and end				
			at lower end				at upper end								
			FAZ* EW sec	MW	VPA Vol.-%	FAG mm/sec	FAZ EW sec	MW	VPA Vol.-%	FAG mm/sec	FAZ EW sec	MW	VPA Vol.-%	FAG mm/sec	
		g/cm³													
1	Polyisourethane (hard)	0.020	6 5 4	5	100	30	24 24 25	25	100	6	25 24 27	26	100	6	Intense dripping
2	Polyisourethane (hard)	0.035	13 13 14 12 13 14	13	100	12	28 33 28	30	100	5	37 38 41 36	38	100	4	"
3	Polyisourethane (hard)	0.045	7 8 7	7	100	21	29 29 27	28	100	5	24 24 26	25	100	6	"
4	Polyisourethane (hard)	0.063	14 13 12 13	13	100	12	27 30 31	29	100	5	28 32 29 30	30	100	5	"
5	Polyisourethane (hard)	0.100	29 28 32	30	100	5	47 42 45	45	100	3	67 67 67	67	100	2	"
6	Polyisourethane (soft)	0.037	32 32 30	32	100	5	—	—	—	—	80 81 78	79	100	2	Intense smoking
7	Polyisourethane (soft)	0.052	34 36 36	35	100	4	—	—	—	—	—	—	—	—	"
8	Foam polystyrene	0.020	16 13	14	100	11	40 38	39	100	4	—	—	—	—	—
9	Foam polystyrene	0.030	27 24	25	100	6	50 49	50	100	3	38 37	37	100	4	—
10	Foam polystyrene	0.050	40 42 40	41	100	4	84 81 84	83	100	2	117 114 116	115	100	1	—
11	Foam rubber	0.136	15 16 17	15	100	10	22 21 23	22	100	7	24 25 24	24	100	6	Intense smoking
12	Foam rubber	0.186	19 20 21	20	100	8	35 34 33	34	100	4	30 33 34	33	100	4	"
13	Urea formaldehyde resin	0.009	—	—	—	—	—	—	—	—	—	—	—	—	Melts
14	Urea formaldehyde resin	0.014	—	—	—	—	—	—	—	—	—	—	—	—	Melts

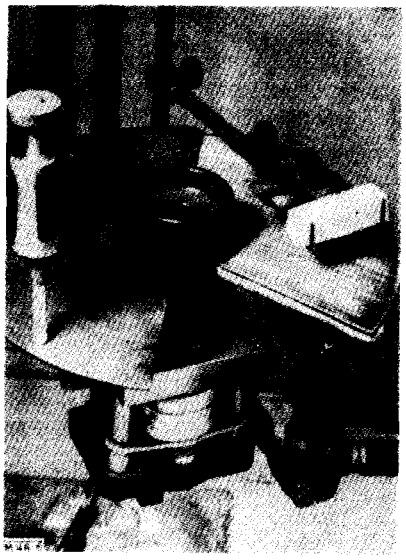
*FAZ - flame propagation time; VPA - proportion of specimen burnt
FAG - rate of flame propagation; EW - single values
MW - mean values

Table IV

Rate of propagation of flames on non-foam materials
Dimensions of specimens: 150 mm x 10 mm
Thickness - see Table

No.	Test material	Specimen thickness	Ignition of specimens												Remarks
			45° angle								Horizontal and end				
			at lower end				at upper end								
		mm	FAZ* EW sec	MW	VPA Vol.-%	FAG mm/sec	FAZ EW sec	MW	VPA Vol.-%	FAG mm/sec	FAZ EW sec	MW	VPA Vol.-%	FAG mm/sec	
A. Plastics															
1	Polyamide foil	0.07	18 22 19	20	100	8	—	—	—	—	21 22 24	22	100	7	—
2	PVC-foil (soft)	0.13	28 23 26	25	90	5	7 8 9	8	50	9	16 13 14	14	20	2	—
3	PVC-foil (hard)	0.10	—	—	—	—	—	—	—	—	—	—	—	—	Melts
4	Acetobutyrate foil	0.03	—	—	—	—	—	—	—	—	—	—	—	—	Melts
5	Polycarbonate foil	0.05	10 8 9	9	50	8	38 35 34	35	60	3	19 23 24 25	23	20	1	—
6	Cellophane foil	0.03	14 19 17	17	100	9	33 34 36 32	33	100	5	34 30 32 31	32	100	5	—
7	Polyethylene foil	0.10	—	—	—	—	—	—	—	—	—	—	—	—	Melts
8	Aminoplast molded mass	2.00	—	—	—	—	—	—	—	—	—	—	—	—	Chars
9	Phenoplast molded mass	2.00	—	—	—	—	—	—	—	—	—	—	—	—	Non-inflammable
B. Textiles															
10	Ticking material	0.23	53 57 55	55	100	3	143 146 139	143	100	1	170 151 160	160	100	1	—
11	Awning material	0.58	70 89 84 86	84	100	2	12 13 14	13	15	2	13 15 16	14	15	2	—
12	Woollen material (100%)	2.20	—	—	—	—	—	—	—	—	—	—	—	—	Tarry smell
13	Woollen mixture (70%)	1.60	77 78 80 83	79	100	2	11 12 14 10	12	10	1	9 8 10 11	9	10	2	Tarry smell
14	Serge lining material	0.14	17 18 16	17	100	9	50 51 52	51	100	3	28 29 26	27	100	6	—
15	Nylon	0.11	—	—	—	—	—	—	—	—	—	—	—	—	Melts
C. Paper, wadding															
16	Filled paper	0.13	19 24 22	22	100	7	—	—	—	—	—	—	—	—	—
17	Newsprint	0.08	8 9 8	8	100	19	49 44 47	47	100	3	32 35 31	33	100	5	—
18	Wadding	approx. 8.0	12 10 12	12	100	12	40 45 44	43	100	4	28 30 32	30	100	5	—

*see Table III



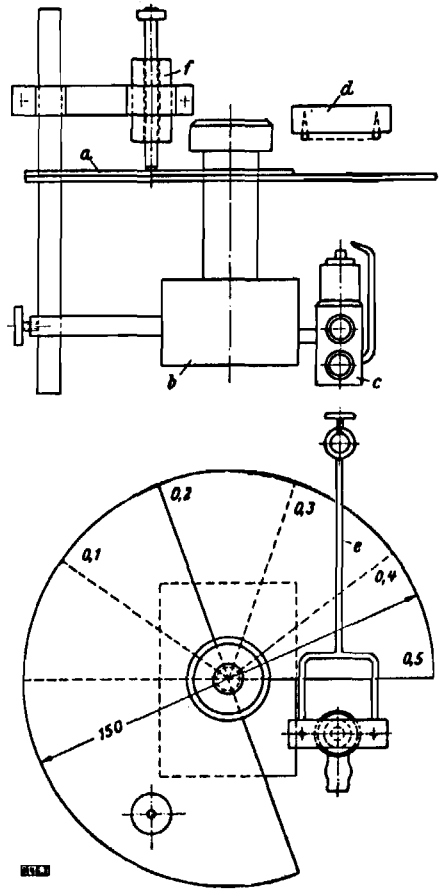


Fig. 1 and 2

Apparatus for testing the inflammability

a - rotating disc; b - motor; c - burner;
d - specimen; e - support
f - locking bolt

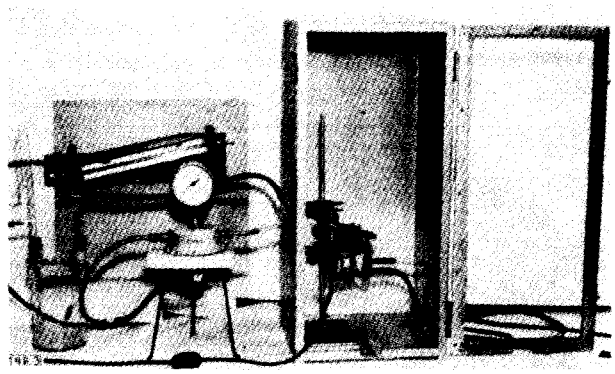


Fig. 3

Apparatus (see Fig. 1) in a special box (with device for throttling the gas pressure)

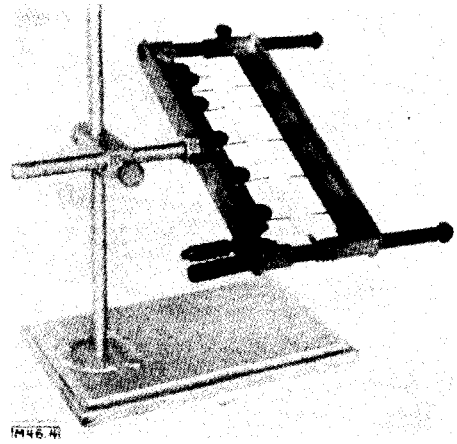


Fig. 4

Apparatus for testing the velocity of flame propagation (with clamped specimen)

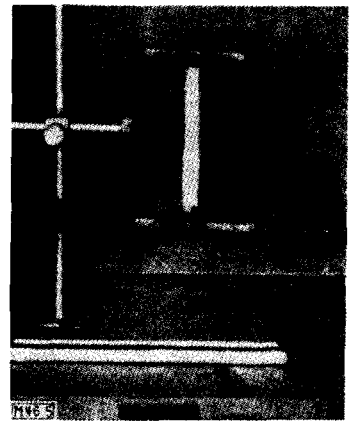


Fig. 5

Apparatus in a special box (Fig. 4)

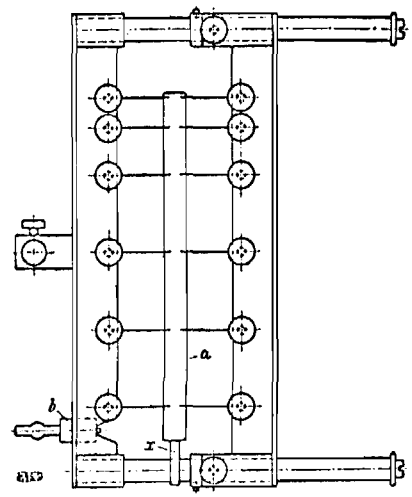


Fig. 6

Apparatus for testing the velocity of flame propagation
a - specimen; b - burner