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A METHOD OF MEASURING SMOKE DENSITY

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A Method of Measuring Smoke Density

The Los Angeles school fire tests confirmed a belief held by many investigators and fire fighters that smoke represents the greatest threat to occupants of a building on fire. The effects on life safety of smoke and other products of combustion are discussed in Section 4, Chapter III, of the *Fire Protection Handbook*, Twelfth Edition.*

Many laboratory methods have been devised for measuring the burning characteristics of building materials. Some of these methods have included procedures for measuring smoke development, but the smoke development data secured by these test methods have suffered from lack of correlation with practical fire conditions. The methods have not been suitable for testing many materials in the form in which they are used in actual applications. The smoke development ratings have been physical ratings on quantity rather than ratings of the degree of obscuration of visibility.

The XP2 Smoke Density Chamber described in this article was designed to burn a small quantity of material in a manner similar to that observed in actual fires. The basic assumption underlying the XP2 procedure is that smoke will be produced only if the material is burning or decomposing in the presence of heat or flame. Therefore, the test specimen is exposed to flame for the duration of the test. The smoke is trapped in the chamber in which combustion takes place.

The smoke chamber is designed to permit the measurement of rate of smoke generation and of its visibility-obscuring effects (density). It does not identify the products of combustion, their irritant or toxic effects.

The test apparatus is self-contained (except for electrical power requirements), is reasonably portable, and is suitable for operation within a standard-size laboratory hood or a well-ventilated room. An illuminated "Exit" sign is incorporated in the chamber to provide a visual correlation between observed conditions and measured results. The XP2 Test Chamber is designed to simulate room conditions where combustibles are burning without producing smoke before the material being tested is added to the fire. Its function is to measure the effect on vision of the smoke produced by the burning or decomposing test material in the atmosphere of the chamber under closed conditions. The chamber is based on the apparatus employed in ASTM D-568-61,† but a hatch, normally closed, has been added to the top of

EDITOR'S NOTE: The test method described in this article was developed by the Rohm & Haas Company in an attempt to meet the demand of regulating officials for a method of determining the smoke-generating potential of plastic materials employed in lighting fixtures. The data cited herein are based on reports prepared by Rohm & Haas Company's Physics Laboratory.

*For reports of the Los Angeles school fire tests, see *Operation School Burning* and *Operation School Burning No. 2*, both available from the NFPA; prices $4.75 and $5.75, respectively. The *Fire Protection Handbook*, Twelfth Edition, is also published by the NFPA, price $17.50.

†"Standard Method of Test for Flammability of Plastics 0.050 In. and under in Thickness."

the chamber. The chamber is instrumented, equipped with a ventilating fan, and provided with a constant, controlled source of ignition.

During the development of the apparatus, several refinements and improvements were made — all for the purpose of obtaining a reasonably realistic and practical means of making comparative evaluations of the smoke potential of a wide variety of combustible materials. It is the hope of the developers of this test method that it will provide the basis for a nationally recognized standard method of rating materials according to their smoke-generating potential. Suggestions for refinements in the test procedure and suggestions as to a suitable method for correlating more closely the results of this small-scale test with actual fire conditions will be welcomed.

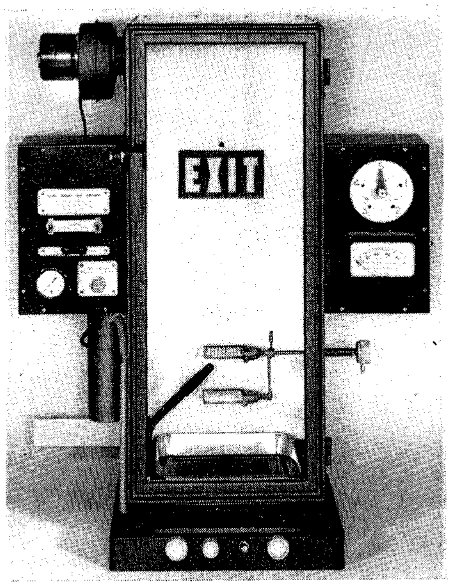


Figure 1. Front view of Rohm & Haas Company's Physics Laboratory Smoke Density Test Chamber.

Description of Apparatus

Test Chamber

Figure 1 is a front-view photograph of the XP2 Test Chamber. Three sides of the 12-inch by 12-inch by 30-inch chamber are constructed of sheet metal with 1-inch-high ventilating openings around the bottom (over-all height 33 inches). One side is essentially transparent to afford a view of the interior of the chamber. The transparent door is hinged so that it can be opened for mounting specimens and igniting the burner. One side of the chamber supports an exhaust fan. The exhaust fan is turned off during the test and allowed to run only to clear out the smoke and fumes between tests. A knob at the front of the cabinet opens the damper and energizes the blower to vent the chamber. A removable white plastic plate is attached to the back panel. This has a clear area through which is seen a white-on-red "Exit" sign. The sign is backlighted with two 6-watt fluorescent lamps.

Specimen Holder

The specimen is supported on a 2½-inch square of 4 mesh, 0.035-inch-gage stainless steel wire cloth. This screen lies in a stainless steel bezel supported by a rod through the right side of the chamber. From the same rod, a similar bezel is located 3 inches lower, supporting a square of asbestos paper which catches particles which may drip from the specimen during the test. The burning specimen may be quenched by rotating the rod and dropping the material into a pan of water.

Smoke Measuring Device

A light source, a barrier-layer photoelectric cell, and a meter are used to measure the proportion of a light beam which penetrates a 12-inch path through the smoke. A grid in front of the photocell is used to protect the cell from stray light. The light source is an automotive lamp with power supplied from a filament transformer and a variable auto transformer. A suitable lens in front of the lamp focuses a spot of light on the photocell. The photometer light beam crosses the cabinet in front of the sign at approximately 11 inches from the top.

Burner Flame

The burner is supported on a swinging arm, which can be operated from outside the chamber. The burner is a Bernz-O-Matic pencil-tip burner (TX–1) with air supplied from outside the chamber through a system of ducts. Flame height is adjusted by means of a needle valve in the base, and the propane pressure at the burner is indicated on a gage in the left-hand panel.

Timing Device

A clock, operated by a switch at the front end of the base, indicates time in minutes and quarter minutes. It is reset to zero by rotating the pointer knob.

Hood

Although not necessary, it is recommended that the test chamber be placed in a hood. The exhaust fan of the hood is turned off during the test and allowed to run only to clear out the smoke and fumes between tests.

Test Specimen

The standard size of the test specimen is 1 inch by 1 inch by ¼ inch. Given the amount of oxygen provided naturally by a chamber of this size and design, this seems to be a practical size for the "standard" test specimen, but considerable work has been done with both larger and smaller specimens. With some materials, however, it is necessary to test the material in the thickness in which it is produced, and, with others, it is necessary to stack specimens to form a composite specimen approximately ¼ inch in thickness. The weight of each test specimen is recorded.

Prior to testing, the specimen is conditioned in accordance with Procedure A of ASTM D618–61.* In this procedure, the specimen is kept for 40 hours in an atmosphere having a relative humidity of 50 ± 2 per cent at a temperature of 23 ± 1°C (73.4 ± 1.8 F).

*Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing.

Test Procedure

Essentially the method of testing consists of burning a weighed sample in the test chamber and measuring the effects of the generated smoke on a beam of light during the test. Steps in the procedure are as follows:

1. At least three test specimens, 1 inch by 1 inch by ¼ inch thick (or nominal use thickness), of each sample are tested. Each specimen is weighed prior to test.

2. The test specimen is laid flat on the screen which is centered in relation to the sides of the chamber.

3. The voltage supplied to the photometer light source is adjusted to produce a reading of 0 per cent light absorbed as indicated by the photometer meter.† An occasional check of zero setting and midrange values should be made with an opaque plate and a calibrated transmission standard.

4. The timer is set at zero.

5. The burner is ignited and the propane pressure is adjusted to 40 psi.

6. The door is closed, the burner swung into place directly underneath the specimen so that the flame contacts the bottom of the specimen, and the timer started.

7. Readings of light absorption are taken at 15-second intervals and observations recorded of the behavior of the material and the obscurement of the lighted sign. Normally, the test is terminated at the end of four minutes.

†Figure 1 shows the meter (lower right dial) with this calibration. The apparatus shown in Figures 2–10 is identical with those in Figure 1 except that the meter is calibrated 0 to 1, with 1 equalling 100 per cent light transmission.

Table 1

Effect of Propane Pressure on Smoke Density

Specimen size: 1 inch by 1 inch by ¼ inch; supporting screen: 2½-inch square of 4 mesh, 0.035-inch gage; sample conditioning: ASTM D618–61, Procedure A.

Pressure (psi)	Maximum Smoke Density (per cent)					Maximum Smoke Production Rate (per cent/min)				
	40	30	20	10	5	40	30	20	10	5
Red oak	2	6	18	53	94	1	2	11	41	67
Ponderosa pine	48	51	45	49	46	44	49	60	69	83
Acrylic sample No. 1	2	2	3	2	2	4	4	4	4	4
Acrylic sample No. 2	4	4	5	5	7	5	5	5	7	10
Acrylic sample No. 3	97	97	97	99	99	114	90	71	69	75
Polystyrene	100	100	100	100	100	296	182	126	120	120
Polyvinyl chloride	100	99	99	98	96	240	196	160	96	90
Polyester, flame-resistant	99	99	99	99	99	151	134	125	115	110
Polyester, glass-fiber-reinforced	89	94	87	91	85	124	128	91	81	66
Plywood with flame retardant coating No. 1	15	33	75	97	91	54	65	100	112	77
Plywood with flame retardant coating No. 2	56	57	78	75	60	23	20	35	31	30
Asbestos millboard	0	0	0	0	0	0	0	0	0	0

By plotting the light absorption data versus time, the smoke production rate (slope of the curve) and total smoke produced (area under the curve) can be determined. Maximum smoke density can be read directly from the curve.

Effects of Variations in Test Procedure

Variations in results caused by changes in certain test conditions were investigated. As is shown in accompanying Tables 1 through 4, the effects in some instances were marked, whereas, in others, they were not. Where these investigations suggested a test condition capable of efficient generalization, this condition was adopted for the standard test procedure. Initially, all decisions as to test conditions were entirely arbitrary.

Conditions described herein as "standard conditions" are those which appear at this point in the development work to be capable of widest application within a chamber having the dimensions and the apertures of the ASTM D–568 chamber. Large-scale tests which are not reported herein have shown sufficient correlation with the results

Table 2

Effect of Specimen Size on Smoke Density

Propane pressure: 40 psi; supporting screen: 2½-inch square of 4 mesh, 0.035-inch gage; sample conditioning: ASTM D618–61, Procedure A.

Sample Size (Inches)	Maximum Smoke Density (per cent)		Maximum Smoke Production Rate (per cent/min)	
	Red Oak	Acrylic Sample No. 1	Red Oak	Acrylic Sample No. 1
1 by 1 by ¼	2	2	1	1
1¼ by 1¼ by ¼	64	5	31	3
1½ by 1½ by ¼	98	2	59	1
2 by 2 by ¼	99	4	91	4

Table 3

Effect of Conditioning on Smoke Density

Propane pressure: 40 psi; specimen size: 1 inch by 1 inch by ¼ inch; supporting screen: 2½-inch square of 4 mesh, 0.035-inch gage.

Conditioning Method	Maximum Smoke Density (per cent) Red Oak	Maximum Smoke Density (per cent) Acrylic Sample No. 1	Maximum Smoke Production Rate (per cent/min) Red Oak	Maximum Smoke Production Rate (per cent/min) Acrylic Sample No. 1
ASTM D618-61, Procedure A*	2	2	1	4
Total Immersion in Water at 73°F for 7 days	46	7	17	8

*In this procedure, the specimen is kept for 40 hours in an atmosphere having a relative humidity of 50± 2 per cent at a temperature of 23 ± 1° (73.4 ± 1.8° C).

obtained in the test chamber under the standard conditions to give the investigators considerable encouragement to believe that extensive large-scale tests would produce results consistent with the results in the small chamber. However, they feel that the results obtained in the chamber under variations of what are referred to as standard conditions are sufficiently interesting to suggest the possibility that a rating of a material might consist of an average of the values obtained under a range of conditions. In fact, they consider one of the principal advantages of this test method to be the fact that variables can be introduced efficiently and economically and a range of values obtained with minimum effort and minimum cost. Thus the ratio of material burned to available oxygen can be altered simply by increasing the size of the specimen. The effect

Table 4

Effect of Supporting Screen on Smoke Density

Specimen size: 1 inch by 1 inch by ¼ inch; propane pressure: 40 psi; sample conditioning: ASTM D618-61, Procedure A.

Screen or Plate	Maximum Smoke Density (per cent) Red Oak	Maximum Smoke Density (per cent) Acrylic Sample No. 1	Maximum Smoke Production Rate (per cent/min) Red Oak	Maximum Smoke Production Rate (per cent/min) Acrylic Sample No. 1
4 mesh 0.035 in. diam.	7	10	3	9
24 mesh 0.020 in. diam.	98	10	148	6
18 mesh 0.016 in. diam.	98	6	132	4
8 mesh 0.016 in. diam.	9	2	6	1
14 mesh 0.035 in. diam.	98	10	210	7
5 mesh 0.041 in. diam.	2	1	3	1
2 mesh 0.043 in. diam.	15	5	5	4
8 mesh 0.062 in. diam.	98	8	143	7
4 mesh 0.106 in. diam.	98	1	116	0.5
0.060-inch sheet perforated with ¼-inch holes	2	2	1	1
cane pattern	98	3	78	1
0.033-inch sheet perforated with 3/32-inch holes	98	13	108	4
1/16-inch aluminum sheet	89	61	65	23
1/16-inch asbestos sheet	93	13	58	4
¼-inch cement-asbestos board	86	35	51	7

Table 5

Smoke Density of Various Materials under Standard Conditions

Specimen size: 1 inch by 1 inch by ¼ inch; propane pressure: 40 psi; supporting screen: 2½-inch square of 4 mesh, 0.035-inch gage; sample conditioning: ASTM D618–61, Procedure A.

	Maximum Smoke Density (per cent)	Maximum Smoke Production Rate (per cent/min)
Red oak	2	1
Ponderosa pine	48	44
Acrylic sample No. 1	2	4
Acrylic sample No. 2	4	5
Acrylic sample No. 3 self-extinguishing	97	114
Acrylic sample No. 4 self-extinguishing	98	123
Polystyrene	100	296
Polyvinyl chloride	100	240
Polyester, flame-resistant	99	151
Polyester, glass-fiber-reinforced	89	124
Plywood with flame-retardant coating No. 1	15	54
Plywood with flame-retardant coating No. 2	56	23
Glass fiber acoustical tile	2	8
Gypsum wallboard	1	0.5
Glass fiber sound-control blanket	13	52
Asbestos millboard	0	0

of slower combustion can be evaluated by changing the intensity of the flame or the size of the mesh of the supporting screen. The effect of flame impingement can be noted by changing the position and/or the method of support of the test specimen. Also, if this is of interest, the flame can be extinguished entirely and the results observed under conditions where the specimen must itself support combustion.

The data obtained when different propane pressures were used are shown in Table 1. In the recommended test procedure, the propane pressure is adjusted to 40 psi. At this pressure, a 1-inch by 1-inch by ¼-inch piece of dry red oak burns without producing a significant amount of smoke (see Figure 2). This observation provides a check on the performance of the burner.

Data obtained by varying the specimen sizes of red oak and acrylic sample No. 1 from 1 inch by 1 inch by ¼ inch to 2 inches by 2 inches by ¼ inch are shown in Table 2. The decision to standardize on 1 inch by 1 inch by ¼ inch was to some extent arbitrary, although this size rather than a larger one was selected because of the low maximum smoke density obtained.

To show the effect of conditioning on smoke density results, red oak and acrylic sample No. 1 were immersed in water at 73°F for seven days prior to testing. The data obtained are presented in Table 3.

The effect on smoke production by red oak and acrylic sample No. 1 when supported by various screens is presented in Table 4.

Typical Test Results

Smoke density data obtained from tests of several samples according to the Rohm & Haas Company's Physics Laboratory Method of Test are summarized in Table 5. Figures 2 through 10 show plots of per cent light absorption as a function of time. Photos taken during the tests are included.

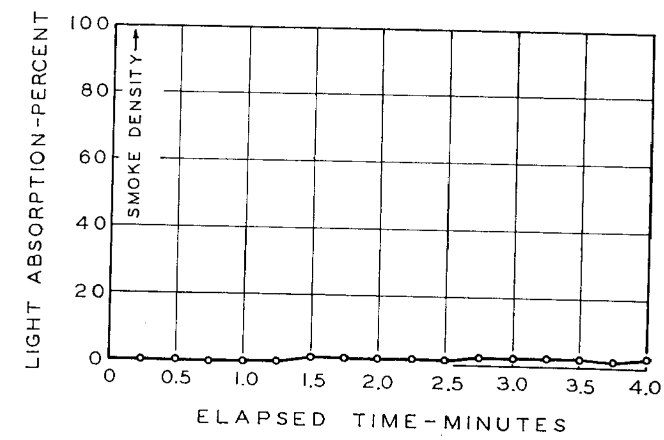


Figure 2. Smoke density test of red oak. Left photo taken at ½ minute; right photo, at 1½ minutes.

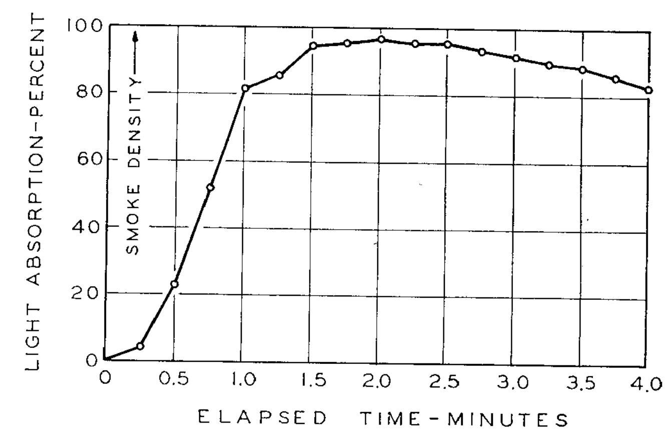


Figure 3. Smoke density test of acrylic sample No. 3. Left photo taken at ½ minute; right photo, at 1½ minutes.

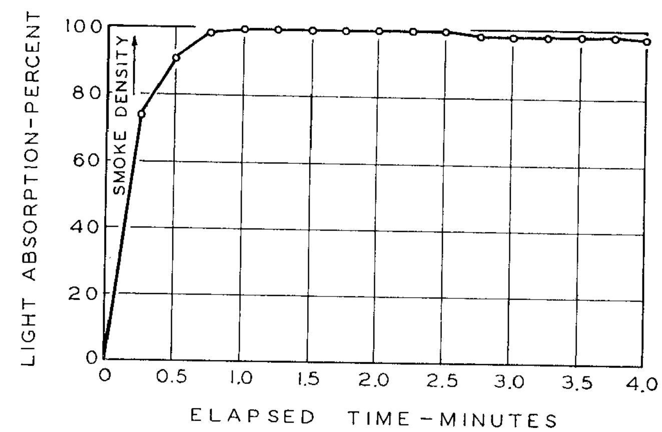
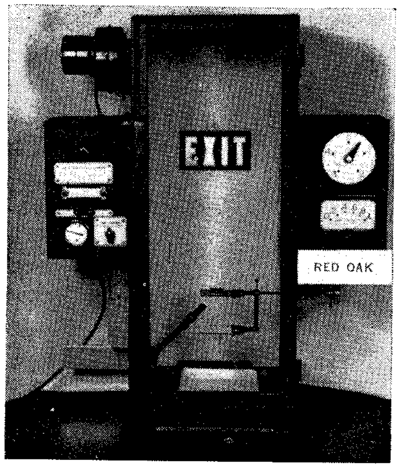


Figure 4. Smoke density test of polystyrene. Left photo taken at ½ minute; right photo, at 1½ minutes.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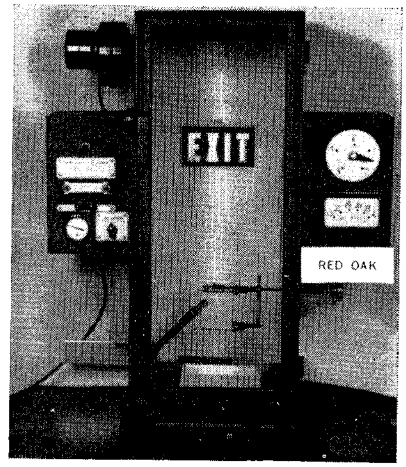
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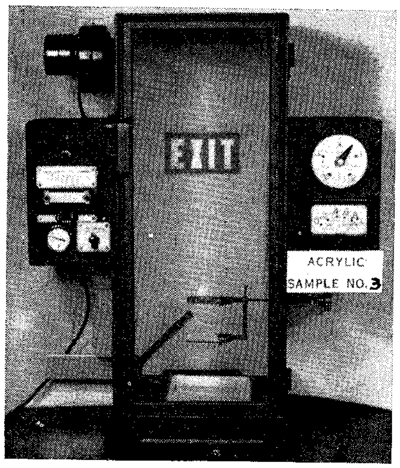
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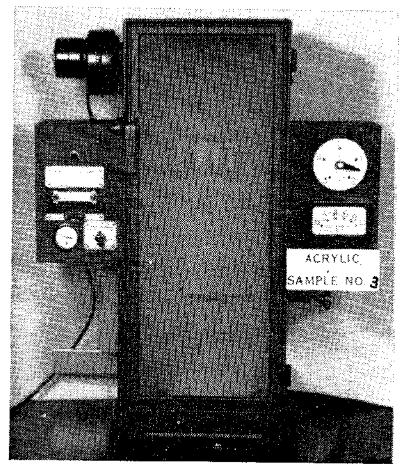
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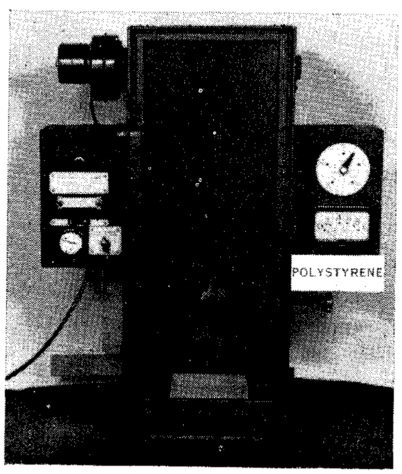
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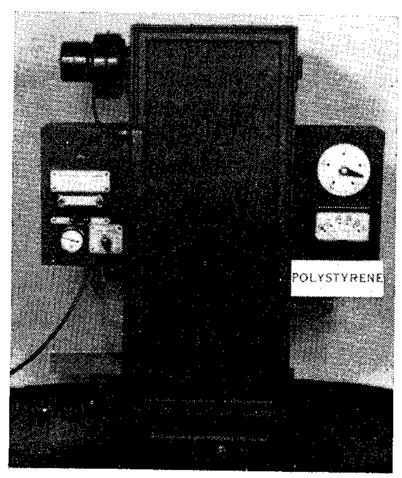
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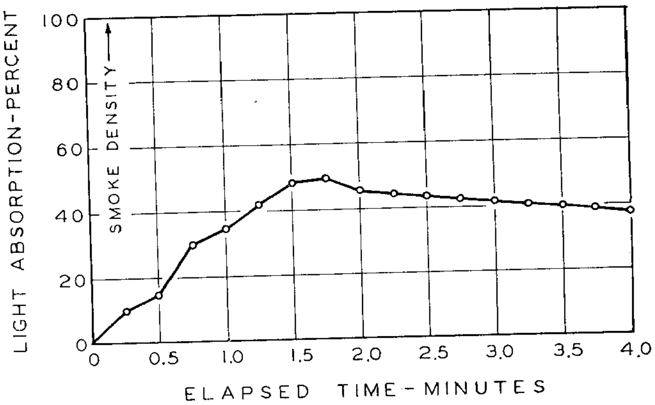

Figure 5. Smoke density test of ponderosa pine. Left photo taken at ½ minute; right photo, at 1½ minutes.

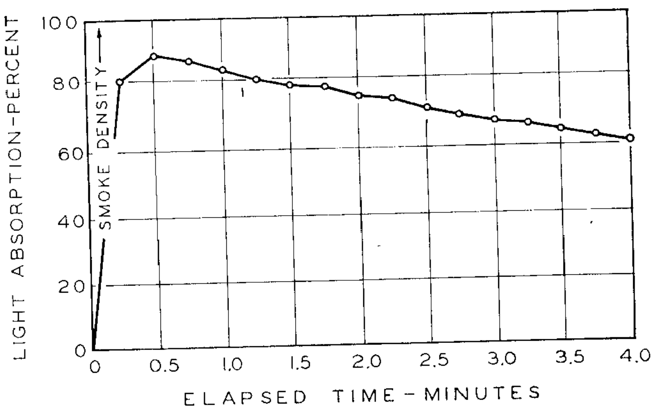

Figure 6. Smoke density test of foamed rubber. Left photo taken at ½ minute; right photo, at 1½ minutes.

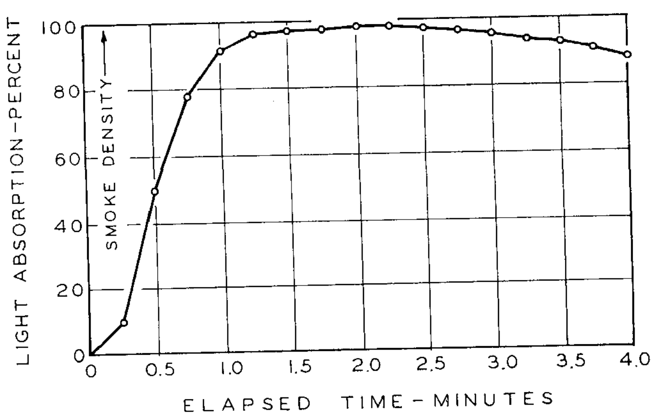

Figure 7. Smoke density test of flame-retardant polyester. Left photo taken at ½ minute; right photo, at 1½ minutes.

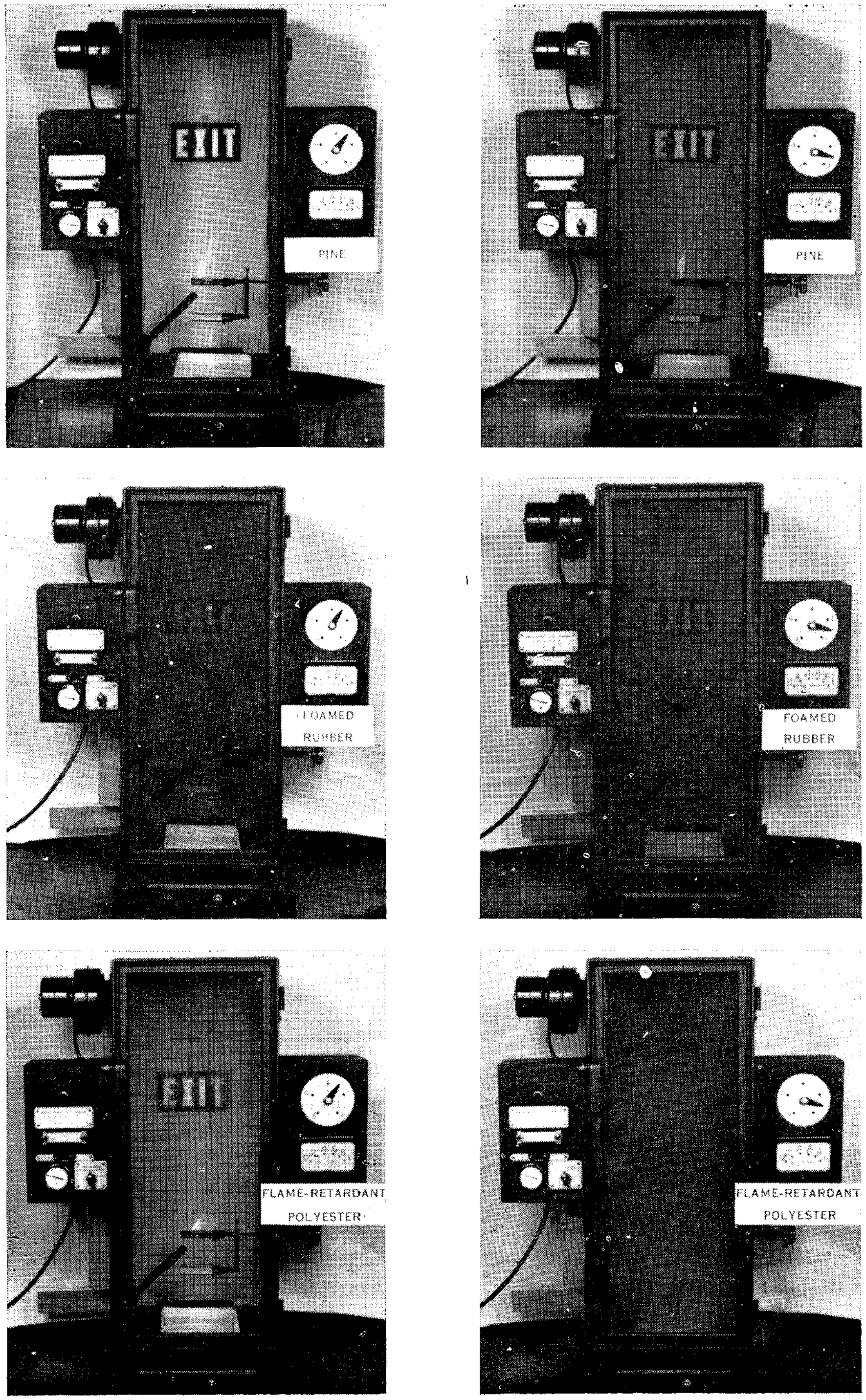
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Figure 8. Smoke density test of polyvinyl chloride. Left photo taken at ½ minute; right photo, at 1½ minutes.

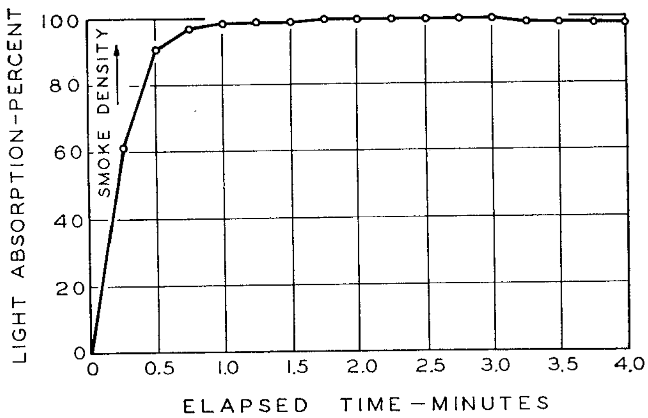


Figure 9. Smoke density test of linoleum. Left photo taken at ½ minute; right photo, at 1½ minutes.

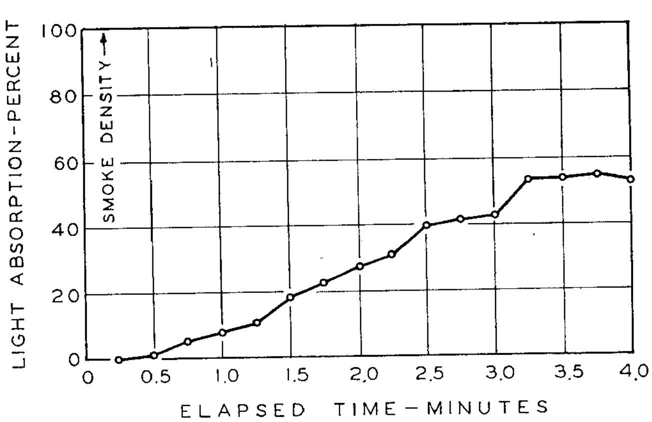
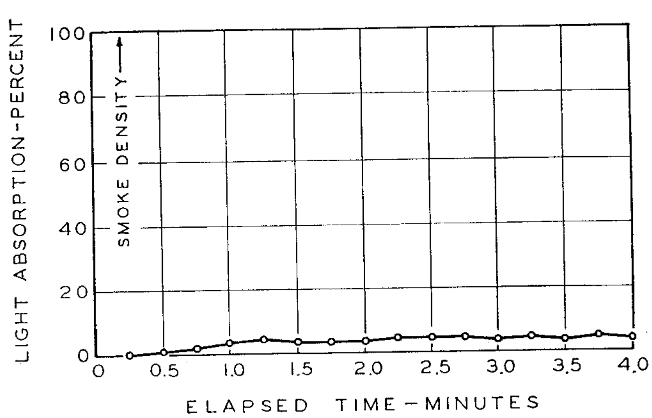
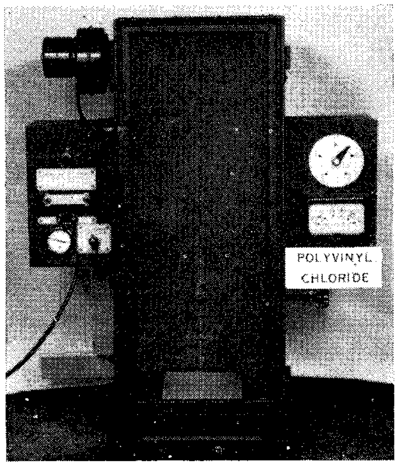


Figure 10. Smoke density test of acrylic sample No. 2. Left photo taken at ½ minute; right photo, at 1½ minutes.

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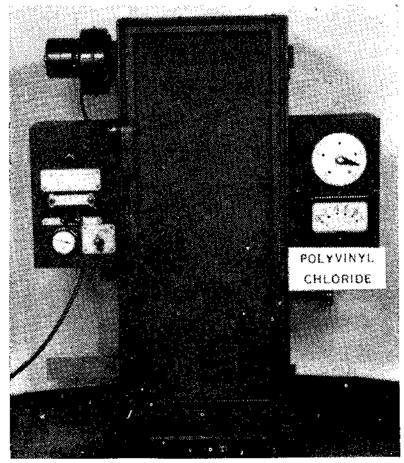
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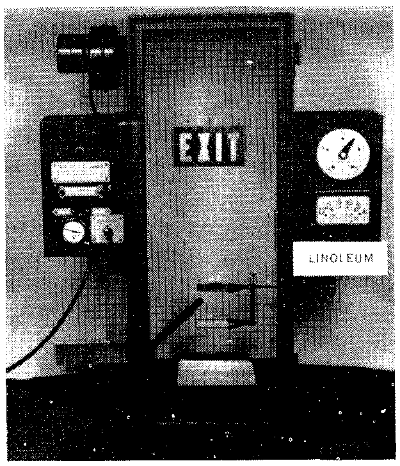
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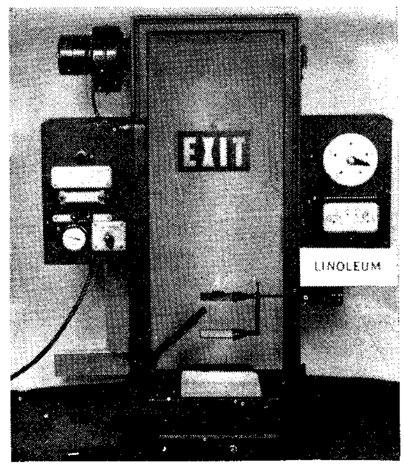
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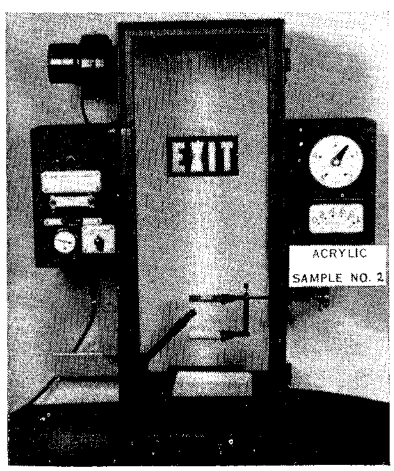
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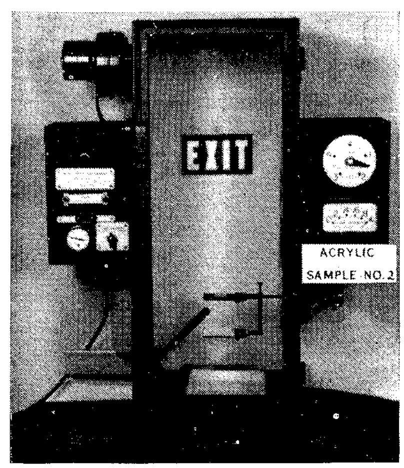
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