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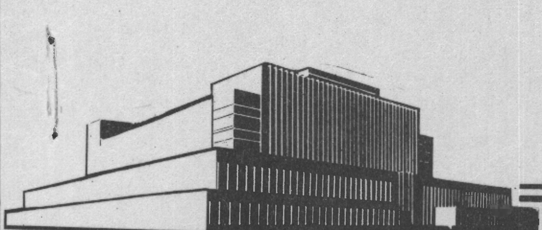

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

SURFACE FLAMMABILITY AS DETERMINED BY THE FPL 8-FOOT TUNNEL METHOD[1]

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Synopsis

One of the more accepted methods for measuring the surface flammability of materials is to observe the flame movement when the test specimen is exposed as the upper horizontal surface of a tunnel furnace. The large tunnel furnace (ASTM Standard E-84) uses this method, but because of the large size of the furnace and specimen, its use is considered impractical in many instances, especially for research and development purposes. Therefore, a small tunnel furnace to measure flame spread was developed by the U.S. Forest Products Laboratory in cooperation with the Housing and Home Finance Agency and ASTM Committee E-5. The resulting 8-foot tunnel furnace uses a specimen 14 inches wide and 8 feet long. The specimen is positioned from the horizontal at an angle of 30° across the short dimension, and 6° along the long dimension, so the test can be performed under natural draft conditions. Heat to induce flaming is supplied by a radiant metal plate below the specimen and by a small ignition flame applied directly against the lower end of the specimen. Order of ranking of the surface flammability of untreated wood products by the small tunnel is generally the same as by the ASTM E-84 tunnel. However, for fire-retardant treated and coated materials, in which flaming is very weak, the direct correlation

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[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

of index values is not good, because the 8-foot tunnel usually produces the higher flame index values. Three 8-foot tunnel furnaces, in addition to the one at the Forest Products Laboratory, are currently in use in research laboratories, and at least three other furnaces are in the process of being assembled.

Introduction

The development of the 8-foot tunnel furnace flame-spread method was started at the Forest Products Laboratory in 1951, in cooperation with the Housing and Home Finance Agency. Many small flame test procedures were then in use, including the fire tube (1),[3] modified Schlyter panel (2, 3), Federal Specification SS-A-118 acoustical tile test (4), and several inclined panel tests (5, 6). A large test method, the Underwriters' Laboratories tunnel furnace, had been made a tentative ASTM Standard E-84 (7) in 1950.

In the large furnace method, a test specimen, 20 inches wide by 25 feet long, was horizontally exposed as the upper side of the tunnel. The flame from a large gas burner was applied at one end of the underside of the specimen under fairly high draft conditions. The exposure time for the flames to travel the length of a red oak standard was 5-1/2 minutes, and the test was normally run for 10 minutes, unless the flames reached the end of the furnace before that time. This time or the distance that the flames travel over the specimen was compared to that of the red oak standard, thereby establishing a relative flame-spread index value. The flame-spread indices for red oak and asbestos millboard have arbitrarily been assigned as 100 and 0, respectively.

It was generally believed that this horizontal tunnel principle and the large scale of this test were desirable for the rating of surface flammability of products used on wall and ceiling surfaces in corridors and hallways of public buildings. For many purposes, however, where large sizes or amounts of experimental material are often difficult and expensive to fabricate and where the costs for making many large-scale tests become prohibitively high, a smaller scale tunnel furnace method was desirable.

This was the reason for developing the 8-foot tunnel furnace flame-spread test. As indicated previously, the original support for this project was furnished by Housing and Home Finance Agency; but, starting in 1953, at

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[3] Underlined numbers in parentheses refer to Literature Cited at end of report.

the conclusion of some initial work on the 8-foot tunnel furnace, sponsorship and encouragement for the completion of this development was provided by the ASTM Committee E-5 on fire test procedures. Groups contributing through this ASTM Committee included Acoustical Materials Association, Insulation Board Institute, Douglas Fir Plywood Association, Gypsum Association, National Mineral Wool Association, Hardboard Association, and the Technical Association of the Pulp and Paper Industry.

Development of the 8-Foot Tunnel

Scientists at the Forest Products Laboratory, working closely with Subcommittee IV of ASTM Committee E-5, developed the present 8-foot tunnel test method during the next 3 to 4 years.

First Model

The original development of the small tunnel furnace was, as shown in figure 1, essentially a scaled-down version of the large tunnel furnace with a horizontally exposed specimen, 15 inches wide and 8 feet in length, with both ignition and heat supplied by the multiorifice burner at a rate of 970 British thermal units per minute. The inside width of the tunnel was 12 inches and the depth could be varied from 7 to 12 inches. The gas flames were applied to the first 24 inches of the specimen, when a secondary air velocity of approximately 120 feet per minute was operating.

Tests were made with the tunnel as originally designed and with several modifications to determine how the flame-spread characteristics of representative materials would be affected. The modifications included changes of contour and depth of the tunnel, burner design and placement, and the rate of secondary air flow.

From this series of investigations, it was apparent that a method would have to be found to establish the leading edge of the flame front more accurately. The shorter the tunnel the more critical it became to know the exact position of the flame front. While a degree of uncertainty may be permissible in a 25-foot tunnel, this could not be tolerated in an 8-foot tunnel. With a horizontal specimen in the 8-foot tunnel under forced draft conditions, the tips of the flame were very irregular, often flickering over a distance of 12 to 18 inches, making the observation of the flame front very difficult. This reduced the sensitivity of the test to an impractical level.

Second Model

Although the flame movement toward the upper edge of an inclined surface or along a horizontal front under forced draft conditions is very irregular because of irregular movement of the burning gases, the flaming at the sides of a burning area is usually quite regular. Therefore, a second model was made of the 8-foot tunnel furnace in which observations could be made of the forward movement of the side of a flaming area. This was done by tilting the specimen upwards 30° across its short axis so the irregular flame tips tended to move to the upper side of the specimen. A slight slope of the specimen was also used lengthwise of the furnace so that the test could be made under natural draft conditions. The flame movement lengthwise in the tunnel, which was the front to be observed, therefore became a regular-shaped, easily located side of the flaming area.

Several other changes were made in this model of the furnace. A steel partitioning plate was placed lengthwise in the furnace, dividing the furnace into two sections--the combustion chamber and the specimen chamber. The lower combustion chamber was heated by the large gas burner and this heat in turn was applied to the specimen by radiation from the partitioning plate. The ignition source was a small, igniting burner at the lower end of the test specimen. Holes were provided along the lower edge of the specimen chamber to introduce the necessary air for the burning of the test specimen. A duct was provided along the entire upper edge of the test specimen to remove products of combustion. These gases were channeled to a central stack where measurements could be made of the amount of heat and smoke contributed for the test specimen. The general appearance of this second model of the 8-foot tunnel is shown in figure 2.

Numerous tests were made with this model of the furnace to determine how the distance between the partitioning plate and the lower edge of the test specimen, the slope of the tunnel, gas consumption rate, and the period of preheating the specimen before testing affected the rate of flammability. Following these initial investigations, standardization of the furnace was established, including the use of a 4° lengthwise slope of the furnace. Tests were made under these conditions on seven materials with matched controls tested in the Underwriters' Laboratories large tunnel furnace.

The actual order of the ranking of these materials by the two methods was approximately the same, and on the untreated wood products the correlation between flame-spread index values was fairly good. However, for fire-retardant-coated fiberboard, fire-retardant-treated plywood and gypsum board, in which any flaming is very weak, the correlation of flame-spread index values was not good. During the rather severe exposure in the 8-foot tunnel furnace, these materials would tend to show small progressive flaming, while in the large tunnel furnace these weak flames were blown out or extinguished by a combination of the combustion gases and high draft conditions.

Because of these differences in flame-spread index values between the two furnaces, a further modification involved the addition of a series of holes in the partitioning plate, lengthwise of the furnace between the lower combustion chamber and the test specimen chamber. It was believed that the rapid movement of the combustion products in the lower combustion chamber to the surface of the specimen would tend to extinguish weak flames in much the same manner as in the large tunnel furnace. Therefore, some further investigations were made using variations of the perforated partitioning plate with the purpose of lowering the index values at the lower range of the scale for fire-retardant and coated materials, and increasing the values at the upper range for products such as untreated fiberboard. This was done by graduating the size of the holes in the partitioning plate, starting from 1-1/2-inch diameter at the ignition end down to 3/8-inch diameter at a distance of 1 foot from the other end.

Third Model

Other conditions that were modified during these tests were a change in the lengthwise slope of the tunnel to 6°, a reduction of the heat in the combustion chamber from 4,000 to 3,400 British thermal units per minute, and no preheating of the radiating plate before the test. A third, or the present model of the tunnel furnace (figs. 3 and 4) was made at this time, where stainless steel was used for the radiating plate, a more efficient smoke duct was incorporated, and some improvements were made in the apparatus for measuring smoke values and heat contributed. The specimen width was also reduced to 14 inches.

Tests were then made on the matched samples from the same seven materials previously included in the Underwriters' Laboratories large tunnel correlating tests. It was found that the values for the gypsum board and fire-retardant-treated plywood decreased to where they were only slightly higher than the large tunnel values. At the upper end of the scale, the values for the untreated fiberboard were not appreciably changed. There were also some inconsistencies on a fire-retardant-coated fiberboard where the large furnace gave an index value of less than that for red oak and the 8-foot tunnel values were higher than for red oak.

Rather complete investigations were then carried out on the effects of operating variations in the 8-foot tunnel furnace using hardboard as a test material. The variables studied included the heat supplied in the combustion chamber, initial plate temperature, distance of lower edge of specimen from hot plate, position of burner in combustion chamber, depth of tunnel, depth and slope of tunnel, density of the red oak standard, and specimen moisture content. The information obtained in these studies on the operational characteristics of the present model of the tunnel is summarized in a previous report in the ASTM Bulletin (8).

Correlation and Evaluations

The flame-spread results obtained by the 8-foot tunnel method were compared with the results of several other methods and also a full-scale fire test. Also, a large variety of lumber, plywoods, hardboards, fiberboards, and particle boards were evaluated for flame-spread characteristics.

Corner-Wall Test

The corner-wall method (3) for the evaluation of flame-spread characteristics of materials was developed at the Forest Products Laboratory and approaches a full-scale test in size. In this method, part of the ceiling and walls in the corner of a room 12 feet long, 8 feet wide, and 8 feet high were covered with the test material. The ignition fire was made up of a standardized wood crib, consisting of 4.95 pounds of conditioned maple sticks, and 50 cubic centimeters of alcohol. After the crib was in place in the corner against the wall panels, it was ignited. Flame-spread index values were computed based on the relative times for the flame to spread up the walls and across the ceiling to two ventilating ducts, located 7 feet from the test corner, as compared to the time required for flames to spread over the surface of a red oak standard. The correlation between the index values in the 8-foot tunnel furnace and the corner-wall method for the 11 materials tested was almost perfect as indicated in figure 5.

ASTM E-84 and Radiant-Panel Methods

In a later series of tests sponsored by ASTM Committee C-20 (9), four models of the large tunnel furnace, the 8-foot tunnel furnace, and the radiant-panel furnace (10) were used for determining the surface flammability for four acoustical materials. The flame-spread index values obtained as a result of the tests are given in table 1. All of the methods were found to rank the materials in the same order. There were, however, considerable differences in the actual flame-spread index values obtained on the matched material, even between the different models of the large tunnel furnace. However, the correlation of results between the 8-foot tunnel furnace and one of the large tunnel furnaces (No. 2), which appeared to be generally representative of the group, was very good. The values for the radiant panel furnace were much higher in the upper range and much lower in the lower range than the values obtained by the other methods.

Los Angeles School Fires

During 1960 and 1961 the City of Los Angeles Fire Department in cooperation with many private and public companies and organizations conducted several series of full-scale fire tests in condemned school buildings. Complete details of these tests are given in two books (11, 12) published by the National Fire Protection Association, Boston, Mass.

In one series of these tests, the flammability of ceiling tile materials was compared by covering the ceiling of a corridor 8 feet wide and 12 feet high with the test material for a distance of 64 feet. The ignition fire load at one end of the corridor consisted of wood cribs varying in weight from 328 to 360 pounds, which were burned to reach a maximum intensity of approximately 18,000 British thermal units per minute in 2-1/2 to 3 minutes. Table 2 gives the maximum distance of flame travel along the corridor ceiling and the flame-spread indices for the same materials as evaluated by the 8-foot tunnel, large tunnel, and radiant-panel methods. A detailed statistical analysis (13) to determine the significance of these data was made for ASTM C-20 Committee, Subcommittee II on Flame Spread Testing. This analysis indicates that the three laboratory methods gave ratings that were indicative of the performance for the materials in an actual corridor fire. It further showed that the 8-foot tunnel gave the best correlation to the corridor performance (correlation coefficient, 0.96), and followed by the radiant panel (correlation coefficient, 0.90) and large tunnel (correlation coefficient, 0.83).

Evaluations of Surface Flammability

The Forest Products Laboratory made an extensive investigation of the surface flammability of 29 species of wood in lumber form and also of 50 commercially produced plywoods, hardboards, fiberboards, and particle boards, using the 8-foot tunnel furnace. The results of these tests were published in Forest Products Laboratory Report No. 2140 (14). During the past year and a half, flame-spread evaluations with the 8-foot tunnel furnace have been made of decorative and fire-retardant paint coatings as applied to Douglas-fir plywood, and also the surface flammability of Douglas-fir plywood treated with some of the basic fire-retardant salts. This work has shown that most of the decorative coatings, when applied in conventional thicknesses, will reduce or have little effect on the surface flammability of the Douglas-fir plywood. The average surface flammability index for the untreated Douglas-fir plywood is 115 in the 8-foot tunnel furnace, and results for the decorative finishes ranged from 86 to 118.

Tests on the fire-retardant paints gave flame-spread index values ranging from 30 to 76, depending upon the thickness of coating applied and the commercial types evaluated. Most of the flame-spread index values for the commercial fire-retardant paints, however, were somewhat higher than the ASTM E-84 values as listed on the paint can labels.

In these recent tests involving the fire-retardant treatment of plywood, the flame-spread index values that were obtained in a corner-wall test, where the crib fire is started directly in the corner, tended to be lower than the values obtained in the 8-foot tunnel furnace. This is in contrast to the earlier tests on untreated wood products where almost perfect correlation was obtained between the two procedures. The reason for this may be that the 8-foot tunnel furnace supplies radiant heat to the test surfaces quite a distance ahead of the actual flaming. This moderate heat causes some of these fire-retardant paints to lose their intumescent characteristics, and therefore increases the flame-spread index values. This condition as developed in the 8-foot tunnel furnace would therefore simulate a condition more closely where a fire starting in the center of the room radiates considerable heat to the wall surfaces before the flames reach this surface.

Flame Propagation Temperature

In a recent series of tests at the Forest Products Laboratory, some data were obtained that provide better understanding of the performance of the 8-foot tunnel furnace. It was frequently observed during tests with the 8-foot tunnel furnace, that the flames will spread down the surface of the test specimen for some distance, hesitate for awhile, and then move ahead; this may be repeated several times during the test period. The points on the test specimens and the times at which the flames hesitate are different for various types of materials, and therefore it did not appear likely that this was caused by nonuniform temperature gradients within the furnace. It was theorized that there is a critical "flame propagation temperature" for each material within the 8-foot tunnel, and when the flames reach a part of the specimen where this critical temperature has not yet been attained, the flames will slow down until there is sufficient radiation from the plate of the furnace to raise the specimen temperature high enough for the flames to progress onward again.

In these studies it was definitely shown that the flames travel over the specimen in the 8-foot tunnel following a definite constant-temperature path. This critical flame propagation temperature was determined for a number of materials as shown in table 3. These "flame propagation temperatures" were inversely related to the flame-spread indices, and it was found possible to determine a mathematical relationship. This relationship is

$y = \frac{33,150}{x} - 15$, where $\underline{y}$ equals the flame-spread index in the 8-foot tunnel and $\underline{x}$ is the flame propagation temperature in degrees F. Figure 6 shows how well the curve for this equation fits the observed data on flame-spread index and flame propagation temperatures for the series of materials that were included in the test.

Frequently, the value for this critical flame propagation temperature can be determined within the first 12 inches of the furnace. Therefore, this work shows promise that in the future it might be possible to develop a flame-spread test method, using even simpler and smaller equipment than the 8-foot tunnel furnace, to relate the surface flammability of wood products to more basic parameters such as ignition temperatures and heat contributed.

Current Procedure

To summarize the current test with the 8-foot tunnel furnace, a 14-inch by 8-foot test panel specimen is first conditioned to constant weight at 80° F. and 30 percent relative humidity. The conditioned specimen is then placed face down within the angle iron frame of the furnace (fig. 3), after the radiant panel of the furnace has first been adjusted to an initial temperature of 85° ± 5° F. The asbestos and metal cover is then placed over the back of the test specimen.

The main gas burner, which is first adjusted to supply 3,400 British thermal units per minute, computed on the basis of the heating value, pressure, and temperature of the gas, is then ignited. At the same time, the small igniting burner, which is supplied with gas at a rate of 85 British thermal units per minute and located so as to apply flame to the first 4 inches of the test specimen, is ignited.

The operator then observes the progress of the flame along the underside of the test specimen through the observation holes in the side of the furnace (fig. 4). Times are recorded as the flame passes each observation station, and other phenomena such as blistering of coated surfaces is noted. Data are also taken throughout the test of the temperatures and smoke density within the stack of the furnace.

The total possible length of flame travel along the specimen is 87 inches, and for red oak lumber of a density of 37 to 41 pounds per cubic foot, the travel time is approximately 18.4 minutes. Flame-spread index values for materials with flames traveling faster than over red oak are based on the ratio of the time to reach the end of the specimen to the time (18.4 min.) required to reach the end of the red oak standard specimens. For flames traveling slower than over red oak, the flame-spread index is based on the ratio of the distance traveled over the specimen, during the standard period for the red oak specimen (18.4 min.), to the total travel distance with the furnace (87 in.).

Fuel and smoke density index values are computed on the basis of areas under test curves as compared to data for the red oak standard, when proper corrections have been made in each for fuel and smoke contributed by the gas burners of the furnace. A detailed description of the 8-foot tunnel furnace and the method for conducting tests are included in the ASTM 1960 Proceedings (15).

Conclusions

The FPL 8-foot tunnel furnace method in its present form is definitely usable for the determination of the surface flame-spread characteristics of materials. Used as a research tool, the furnace is providing information on how surface flames for different materials tend to follow definite constant temperature paths. Also, a study of a number of fire-retardant coatings that were evaluated by using the 8-foot tunnel and the corner-wall flame-spread methods has shown a significant difference between the flame-spread index values at the lower range of the scale for the two methods.

The present model of the 8-foot tunnel furnace has been standardized, but future work may include studies of minor changes in the operating procedures such as gas rate, furnace slope, tunnel opening, test interval, and other modifications to result in better agreement between test methods. Also, methods of analyzing these data will be studied with the purpose of expanding the flame-spread scale at both the high and low ranges.

During the past year, 8-foot tunnel furnaces of the FPL design have been completed at the Simpson Timber Company in Bellevue, Wash., the

Armstrong Cork Co., at Lancaster, Pa., and the United States Plywood Corporation at Brewster, N. Y. All these furnaces are currently in operation, and a correlation test program is being established between the four laboratories. Three or four other laboratories are now considering the installation of 8-foot tunnel apparatus.

As more work is done with the four furnaces now in use, other desirable modifications may be suggested. These suggestions will be evaluated and, if found useful, modifications in the method will be made.

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(10) American Society for Testing and Materials. "Surface Flammability of Materials Using a Radiant Heat Energy Source," ASTM Standard E162-60T.

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(13) Everett J. Reichman, "Analysis of the Results in Operation School Burning 2A," Report to ASTM C-20 Committee, Subcommittee II on Flame Spread Testing, 1962.

(14) H. D. Bruce and L. E. Downs, "Surface Flammability of Various Wood-Base Building Materials," Forest Products Laboratory Rpt. No. 2140, May 1959.

(15) American Society for Testing and Materials. "Proposed Method of Test for Surface Flammability of Building Materials Using an 8-Foot Tunnel Furnace," Proc. American Society for Testing Materials, Vol. 60, pp. 462-467 (1960).

Table 1.--Comparison of Flame-Spread Index Values[1] for Acoustical Materials in ASTM C-20 Round Robin Tests--1959

Tile	Rank	Large tunnel furnace				8-foot tunnel furnace	Radiant panel furnace
		1	2	3	4		
W	(4)	357	221	130	109	182	415
X	(1)	16	16	40	8	21	4.6
Y	(3)	177	144	82	62	137	94
Z	(2)	88	105	86	59	101	36

[1]Each value is the average for 2 to 4 tests.

Table 2.--Maximum distance of flame travel in Los Angeles School ceiling fire tests[1] and flame spread indices determined by three methods

Material	Distance of flame travel	Flame spread indices: 8-foot tunnel	Flame spread indices: ASTM E-84 large tunnel	Flame spread indices: ASTM E-162 radiant panel
	Ft.			
3/4-inch textured glass fiber mineral tile	10	3	5	4
5/8-inch random-perforated mineral acoustic tile	15	2	8	3
5/8-inch fissured and finely perforated cellulose acoustic tile, integrally treated	18	45	21	2
3/4-inch random-perforated cellulose acoustic tile, surface-treated	25	83	92	46
3/4-inch finely perforated cellulose acoustic tile, surface-treated	30	85	87	44
13/16-inch red oak, tongue and groove	35	100	100	100
3/4-inch random-perforated cellulose acoustic tile	37	135	77	152

[1] "Operation School Burning No. 2" by Los Angeles Fire Department, Published by National Fire Protection Association.

Table 3.--Flame-spread index values and flame-propagation temperatures for various materials as determined in 8-foot tunnel furnace

Material	8-foot tunnel flame spread index	Flame propagation temperature
		°F.
Asbestos board	0	....
Douglas-fir plywood, monoammonium phosphate treatment	16	888
Douglas-fir plywood, fire-retardant paint A	25	522
B_1	46	559
B_2	51	551
C	57	493
B_3	62	518
D	69	428
Fiberboard A, fire-retardant paint B_4	79	446
Untempered hardboard	97	290
Tempered hardboard	104	287
Red oak	106	260
Cottonwood	108	249
Douglas-fir plywood	119	261
Laminated paperboard	126	233
Fiberboard B	136	220
Asphalt-coated sheathing	138	227
Asphalt-impregnated sheathing	159	193
Fiberboard A	170	193

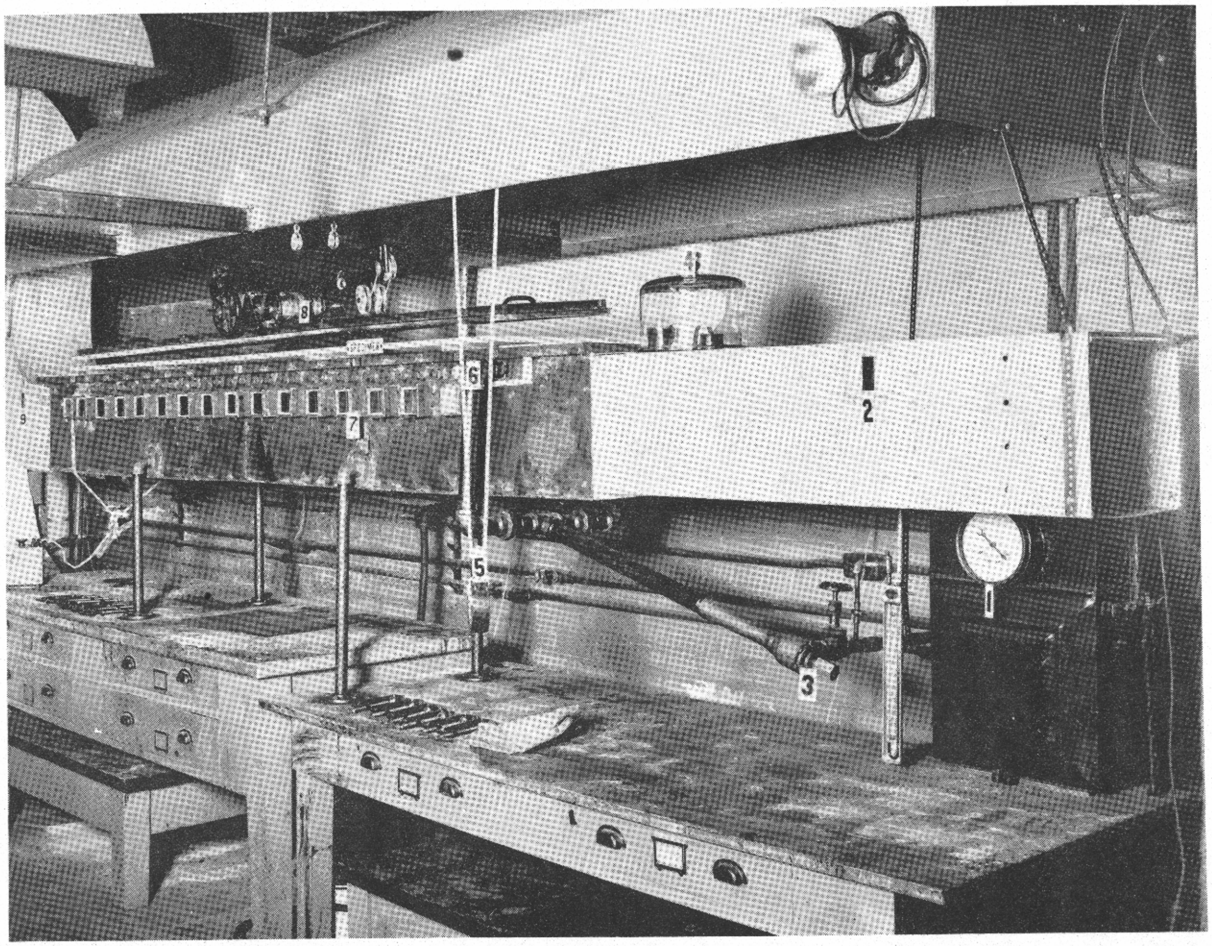

Figure 1.--The original 8-foot tunnel furnace with cover raised and a test specimen supported on stickers above the tunnel. The numbers referred to in describing the tunnel indicate (from right to left) the location of the following pieces of apparatus: (1) Gas meter, (2) slot used in calibrating velocity indicator, (3) gas-air mixture, venturi, and needle valve control, (4) air velocity indicator, (5) damper regulator, (6) burner extension, (7) observation ports, (8) apparatus for lifting cover, (9) slot used in calibrating velocity indicator (same as 2), and (10) damper.

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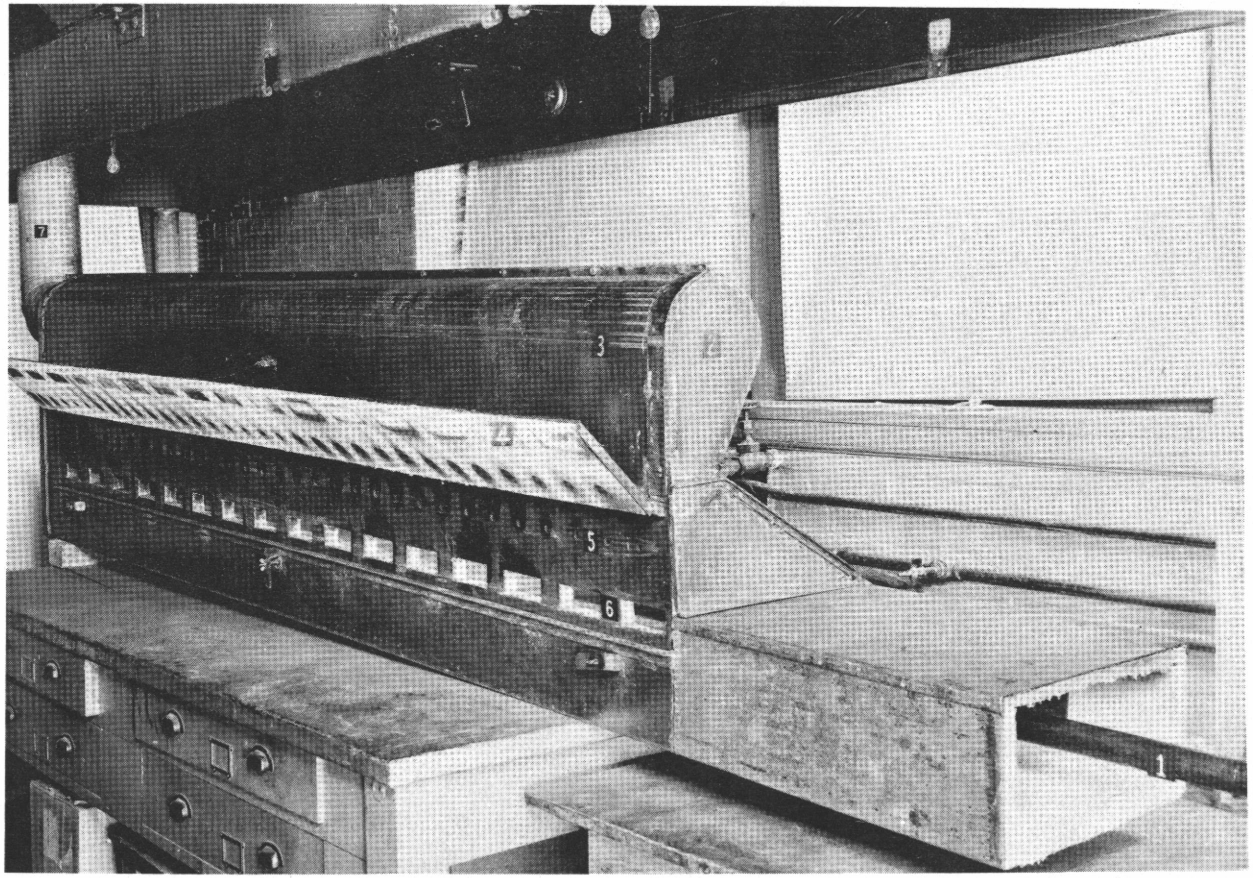

Figure 2.--Observer's side of the second model of the 8-foot tunnel furnace. The numbers (from right to left) indicate the following features: (1) Pipe supplying gas to a T-head burner in the firebox, (2) removable end plate, (3) chamber for collecting flames and hot gases from the burning specimen, (4) hinged cover to shut off the supply of oxygen to the specimen at the end of the test, (5) row of 1/2-inch diameter holes for observing flame spread on the specimen, (6) row of 1-1/2- by 4-inch holes to admit air for combustion of the specimen. The horizontal hot plate partition that forms the ceiling of the fire box can be seen through these holes, and (7) flue pipe for discharging combustion products under the laboratory hood.

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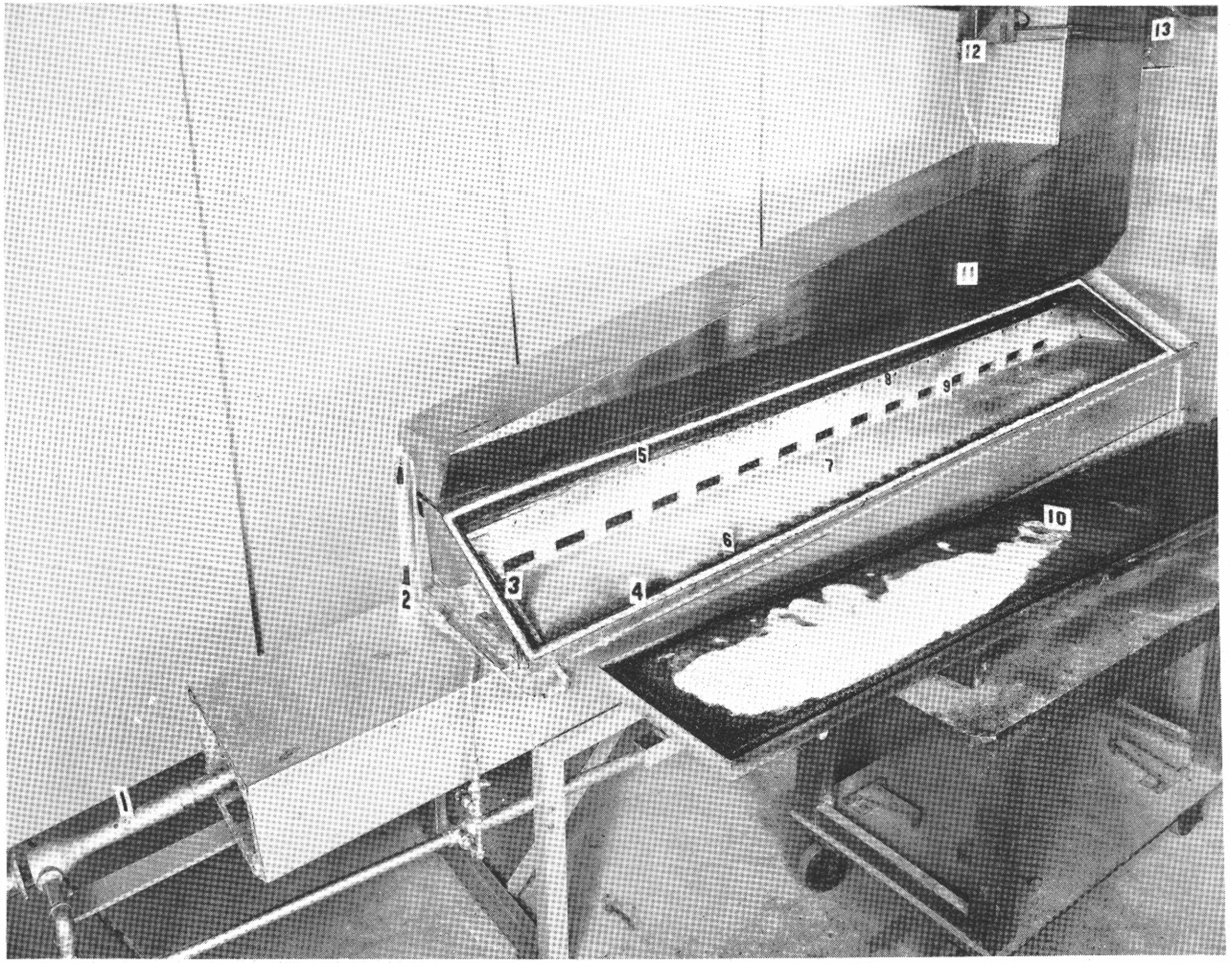

Figure 3.--Specimen side of present model of 8-foot tunnel furnace. (1) Tunnel burner in firebox, (2) ignition burner flow meter, (3) ignition burner, (4) sand to seal cover, (5) angle iron specimen holder, (6) holes in hot plate inset with Meker burner tops, (7) hot plate over firebox, (8) flame progress observation ports, (9) natural draft air inlets, (10) specimen cover, (11) collecting hood for combustion gases and smoke, (12) photoelectric equipment for smoke density measurements, and (13) thermocouple for stack temperature measurement.

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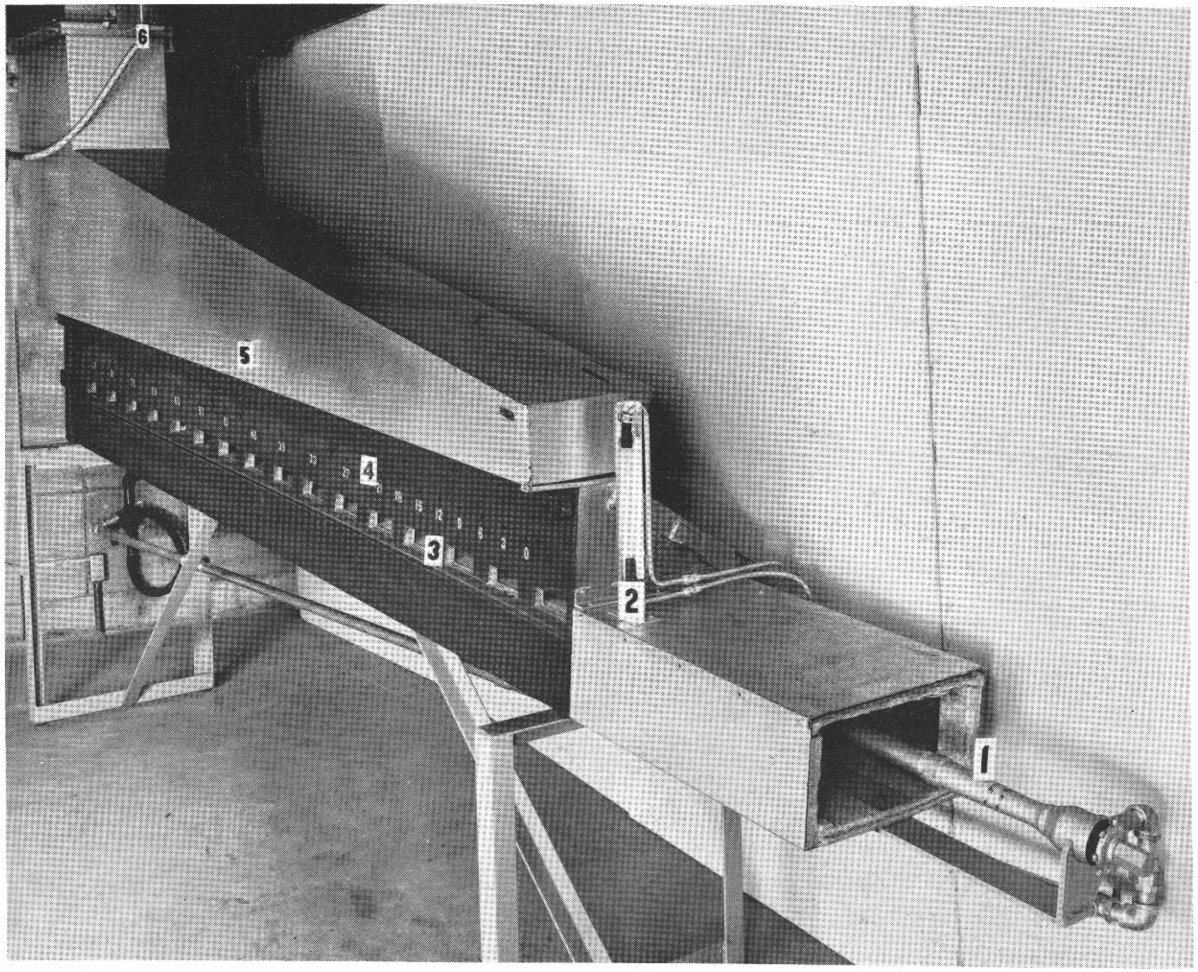

Figure 4.--Observation side of present model of 8-foot tunnel furnace. (1) Tunnel burner in firebox, (2) ignition burner flow meter, (3) natural draft air inlets, (4) flame progress observation ports, (5) collecting hood for combustion gases and smoke, and (6) photoelectric equipment for smoke density measurement.

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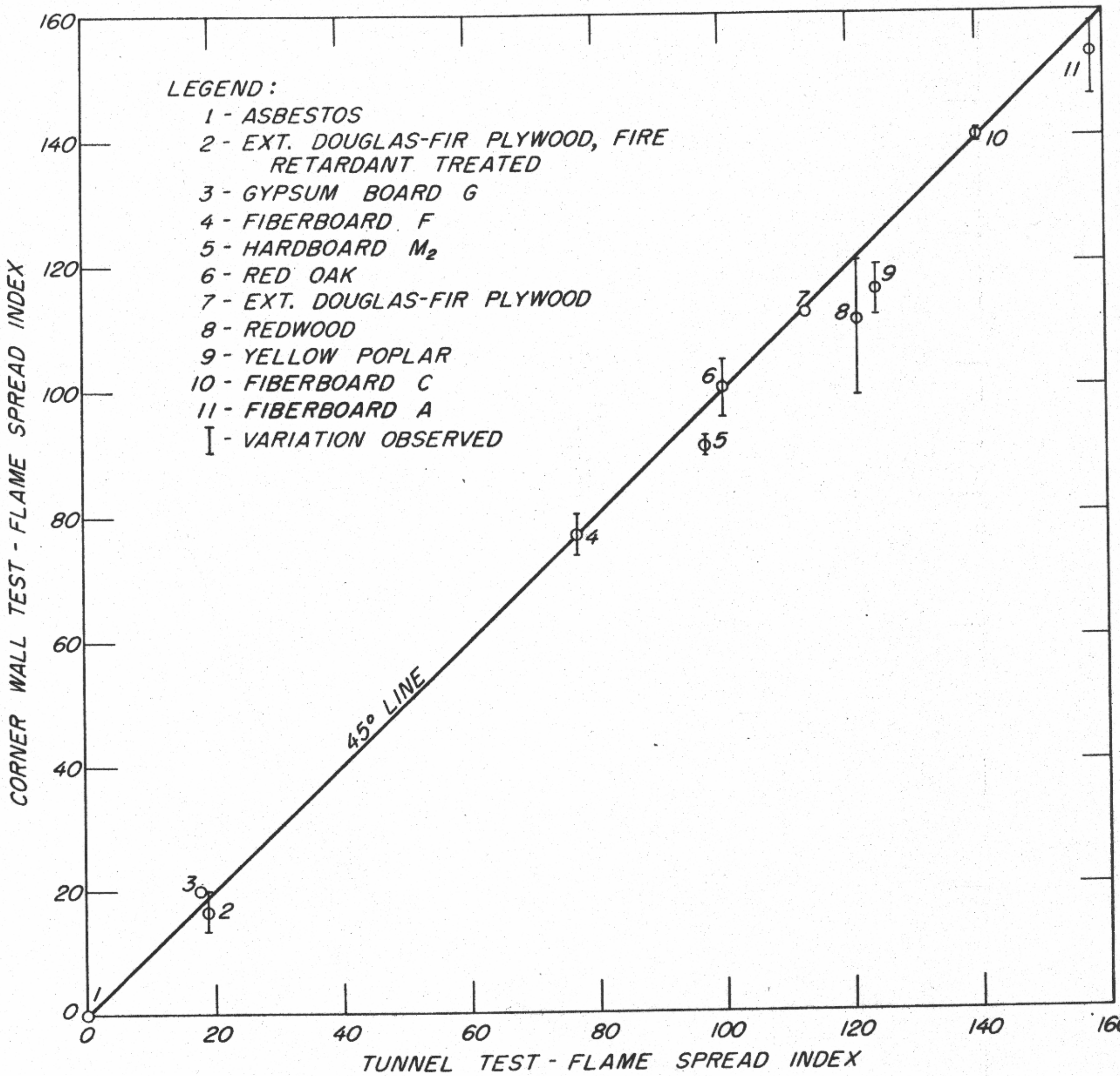

Figure 5.--Comparison of flame-spread indices from the FPL tunnel furnace and corner-wall fire tests.

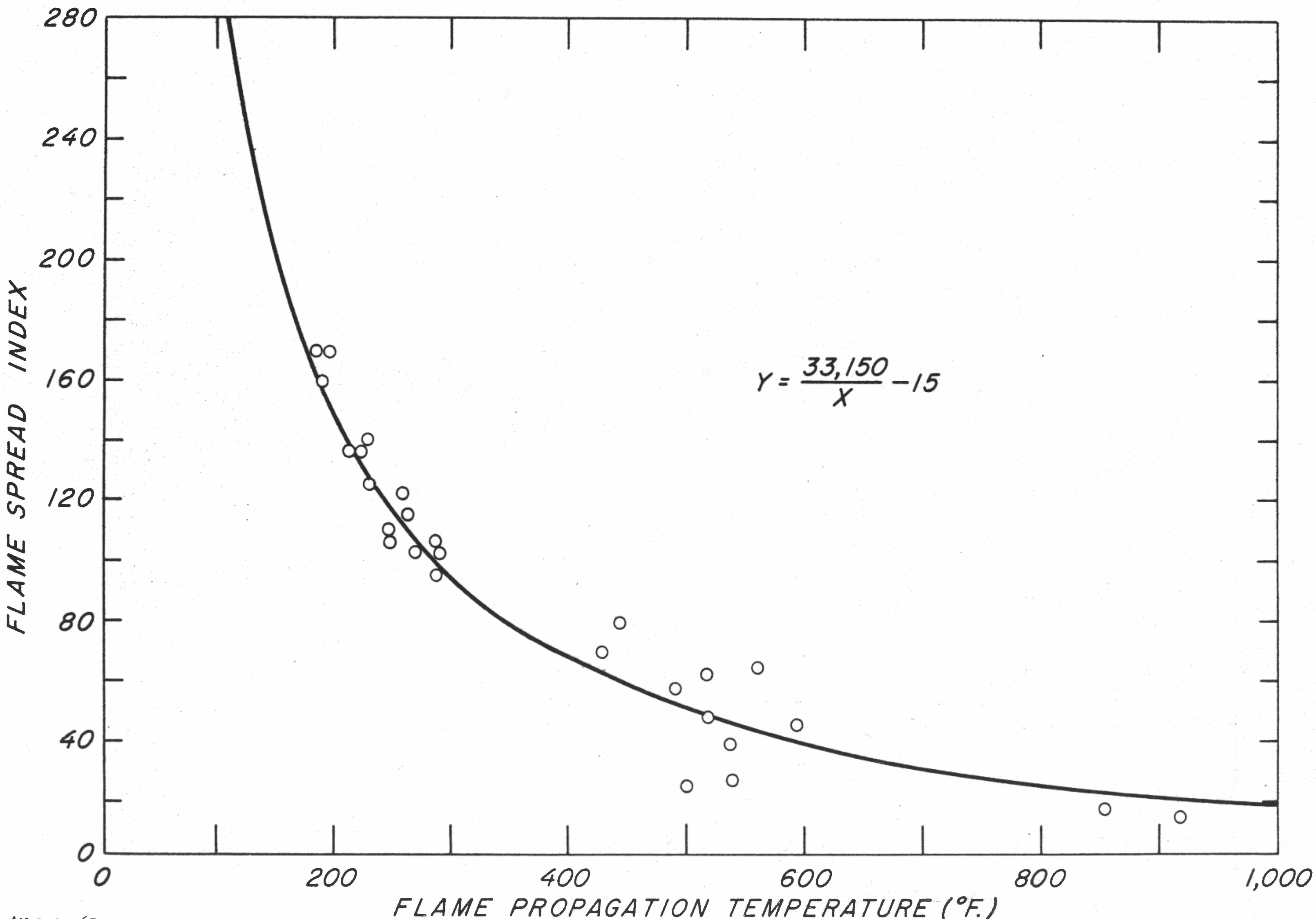

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Figure 6.--Curve and formula relating flame-spread index and flame-propagation temperature.