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The Effect of Sample Orientation in the Smoke Density Chamber

Leslie Breden and Marts Meisters

Center for Fire Research
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***

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THE EFFECT OF SAMPLE ORIENTATION IN THE SMOKE DENSITY CHAMBER

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Abstract

Smoke measurements were compared for various materials in the vertical and horizontal positions. There appeared a significant difference for thermoplastic materials because of the melting away from the incident heat flux in the vertical position. The horizontal mode in addition allows one to relate the chemistry of polymeric materials to the amount of smoke production. Finally, smoke measurements are made of products containing various amounts of smoke suppressants.

Key words: Fire performance; horizontal and vertical smoke measurements; smoke; smoke density chamber; smoke suppressants.

1. INTRODUCTION

It has been accepted by code and fire officials that smoke resulting from a fire is hazardous [1][1]. Traditionally, this hazard has been defined in terms of light obscuration, which has been related to the ability of a person to locate a door, read an exit sign, recognize contrasting surfaces in order to escape, or locate victims for rescue by fire personnel. This was emphasized by the following observation from Operation School Burning No. 2 [2].

> "Smoke itself does not contain a high enough concentration of dangerous gases to be lethal in the early stages of a fire. However, the untenable smoke, by its irritant properties and its obscuration of normal visibility does immobilize the occupants within the area of the building where they happen to be located. They are then trapped within the building and unless rescued promptly, may be killed by lethal heat and gases which follow shortly."

Unfortunately, the presence of toxic species, physiological and psychological effects have not yet been adequately defined so that obscuration has remained the principal factor in assessing smoke hazard [3,4].

The most widely referenced method in building codes, for measuring smoke, is the American Society for Testing and Materials (ASTM) Standard Test Method E-84-70 [5]. In this test, samples of materials are burned and light attenuation measurements are taken through the combustion products when they are exhausted from a tunnel at a controlled velocity. The data from this test can provide information about smoke production rate, time to achieve maximum value, duration of maximum smoke production and a total smoke volume over a test period. The ceiling mounting position of the specimens causes poor reproducibility for materials that melt and drip. This test method has been used primarily for building construction materials.

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[1] Numbers in brackets refer to the references listed at the end of this paper.

Another test which is gaining acceptance for measuring smoke from building construction materials and other products is the Smoke Density Chamber [6]. This method measures light obscuration by smoke from a vertically mounted 7.6 x 7.6 cm specimen burned in a closed 0.5-cubic meter chamber. The specimen is exposed to a radiant heat flux of 2.5 W/cm^2, as shown in figure 1. This illustrates the heat flux distribution on the sample with lower heat flux areas in the corner. Smoke measurements are expressed in terms of maximum specific optical density (D_m) for flaming and non-flaming exposure conditions:

$$D_m = \frac{V}{AL} \log \left(\frac{100}{\%T}\right),$$

where

V = Chamber volume

A = Specimen area

L = Light path length

T = Minimum light transmittance

The vertical sample mounting simulates a wall of a burning enclosure and has been used primarily for evaluating construction materials such as wood and gypsum board. Problems occur when the procedure is extended to include thermoplastics and other materials that melt and can drip during heat exposure. Logically, then, the most useful extension of the procedure may require modification of the sample mounting system. One obvious alternative is use of a horizontal mounting system. This paper reports some observations of the effects of the horizontal sample orientation in the Smoke Density Chamber.

2. SMOKE DENSITY CHAMBER MODIFICATIONS

2.1. Horizontal

As part of a continuing effort in the development of the Smoke Density Chamber, it was observed that the maximum smoke production (D_m) of polystyrene in the flaming mode ranked significantly below that from ABS and rigid PVC [7]. However, when samples of equal weights of these materials were burned openly in the laboratory, polystyrene appeared to produce greater quantities of smoke than either PVC or ABS. This anomaly can be explained by observing the melting and dripping of polystyrene from the vertical holder, as shown in figure 2. Because polystyrene melts and drips from the holder more rapidly than either the PVC or ABS, it is not as completely burned, based on initial sample weight.

To overcome this melt difficulty in the vertical specimen holder, a small trough and multi-directional burner, as shown in figure 3, was developed for use with thermoplastic materials [8]. This addition was designed to trap the melting material from these specimens in the trough and burn it completely. However, when the material was in the trough, it was blocked from the radiant source and was not completely pyrolyzed or was pyrolyzed under a less intense heat flux. This problem was illustrated by burning equivalent amounts of polyethylene in the vertical holder and in the trough. An 8.7 gram sample was tested in the standard configuration under the flaming mode; however, only 3.7 grams were consumed before the sample had dripped from the holder. The D_m was 69. Next, 3.7 grams were placed directly in the trough and burned using the multi-directional burner and the radiant heater. The entire sample was consumed but produced a D_m value of only 14. This indicated lower smoke

Top

1.65

2.33

2.30

2.08 2.34 2.55 2.62 2.58 2.40 2.14

2.45

2.16

1.55

← 6.4 cm →

Figure 1. Vertical Flux Distribution W/cm^2

Figure 2. Excess Melt-Drip from Pan

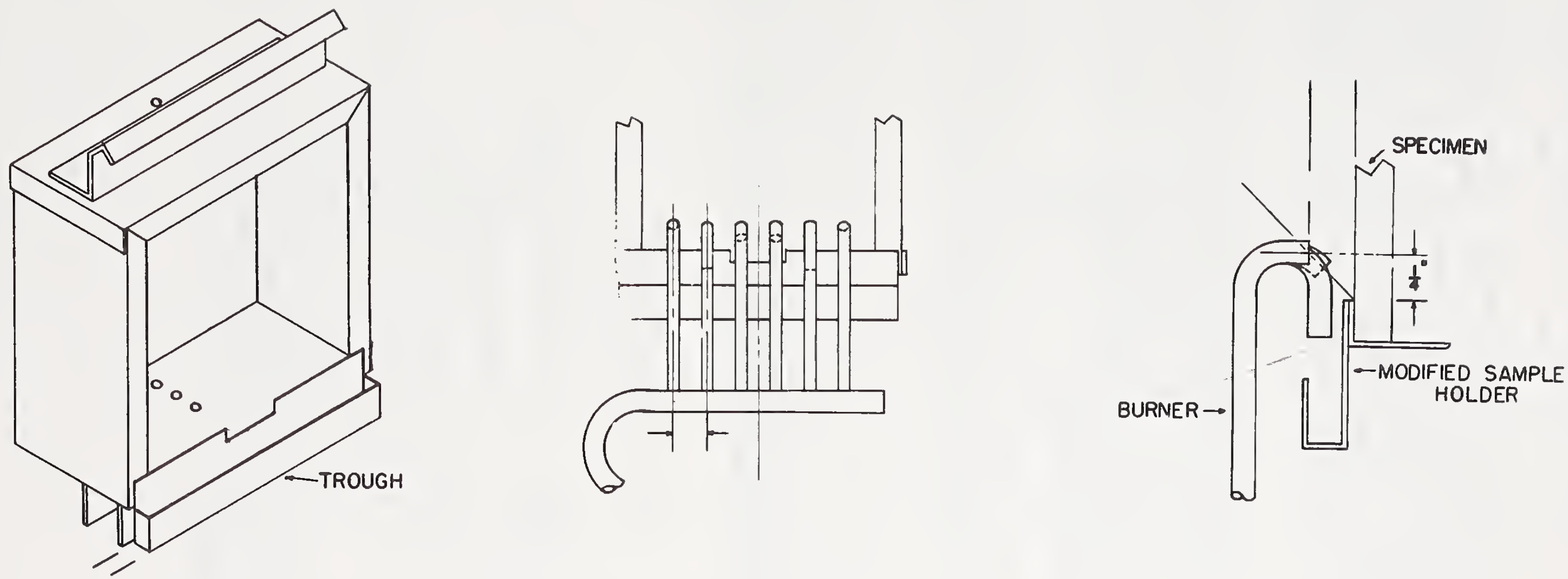


Figure 3. Modified Vertical Holder

production from an equal weight of sample as it burned in the trough rather than in the vertical holder. Clearly, the smoke generation characteristics depend to some extent on whether or not the sample remains intact and is exposed to 2.5 W/cm^2 external heat flux for the duration of the test.

Based on these preliminary experiments, a horizontal sample holder and heater configuration was constructed for the Smoke Density Chamber, as shown in figure 4. The heaters are standard Smoke Density Chamber units with the wire elements repositioned 3.8 cm closer to the front so as to decrease the sample to heater distance. Two heaters inclined at 60° from the horizontal minimize smoke impingement which occurs if a single heater is used parallel to the sample surface. A water-cooled load cell is incorporated for continuous mass burning rate measurements. Flaming exposure is provided by a single burner.

Initial sample surface to heater distance was maintained constant at 0.6 mm regardless of the sample thickness by a lab jack under the load cell, as shown in figure 4. In general, the radiant flux distribution on the sample was $\pm$ 10% of the nominal 2.5 W/cm^2, as indicated by figure 5. Calibration was accomplished by substituting a water-cooled radiant flux meter, 0.46 cm in diameter, for the load cell and adjusting the lab jack so that the meter corresponded with the sample height.

Solid specimens up to 7.6 x 7.6 cm can be accommodated in the modified Smoke Density Chamber. The backs and sides of the samples are covered with aluminum foil but the surface is left totally exposed. Liquids or powders can be burned in aluminum weighing dishes.

2.2. Horizontal Configuration and Load Cell

A load cell incorporated in the horizontal configuration can be used to explore alternative approaches for measuring smoke properties of materials. Seader [9] has proposed the mass optical density concept expressed by the equation

$$MOD = \frac{V}{LM} \log \frac{100}{\%T} ,$$

where

MOD = Mass optical volume

V = Chamber volume

L = Light path length

M = Mass lost up to some %T

T = Light transmittance

The fundamental difference between mass optical density (MOD) and specific optical density (D_s) is the use of mass burned rather than area burned as the sample correlating parameter.

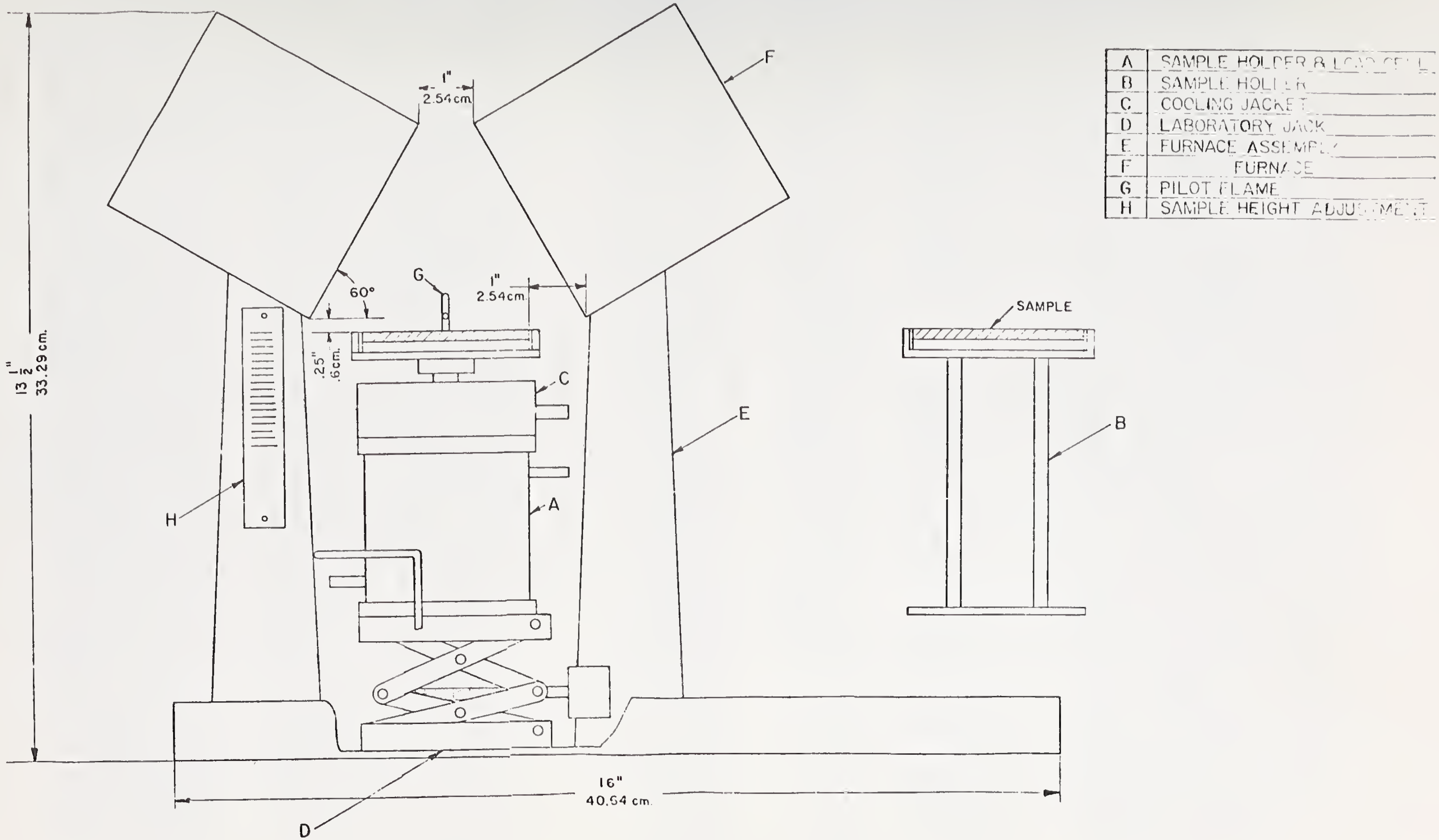


Figure 4. Horizontal Configuration

	2.34	2.28	2.36
Left	2.57	2.50	2.57
	2.38	2.20	2.33

← 7.6 cm →

Figure 5. Horizontal Flux Distribution W/cm^2

3. RESULTS AND DISCUSSION

3.1. Comparison of Vertical vs Horizontal Configurations

After construction of the apparatus, a comparison was made of the D_m values for materials of the same thickness (.15 cm) tested in both the vertical and horizontal configurations. A summary of the results obtained in the flaming mode with an irradiance of 2.5 W/cm^2 on the sample appears in table 1. It is significant to note the large differences between the vertical and horizontal D_m values when the sample materials have a thermoplastic character. When materials of this type, such as nylon or polypropylene, were burned in the vertical position they melted and flowed out of the externally applied flux field. Thus, the D_m values were much lower in the vertical position for a given initial weight of thermoplastic material.

Better data correspondence is evident in the case of non-thermoplastics tested in the horizontal and vertical modes. This is not surprising because these materials remain intact for the duration of the test. Small differences which are observed may be attributed to sample holder designs and other factors such as experimental repeatability which have not been fully evaluated.

The horizontal configuration also improves data repeatability for thermoplastics. Table 2 lists the results for polystyrene tested under flaming exposure conditions in the vertical and horizontal modes. A coefficient of variation of approximately five percent can be obtained routinely for thin samples tested horizontally.

One fundamental difference between the horizontal and vertical sample exposure is illustrated in figure 6. In general, materials burn more rapidly in the horizontal than in the vertical mode. This may be at least partially attributed to the heat sink effect of the larger metal holder used for vertical testing. In the horizontal mode, the sample rests directly on a preheated asbestos-cement board block.

3.2. Effect of Additives

Another area where the smoke density chamber has been useful is in analyzing the smoke contribution by various components of a product to the total smoke value. Figure 7 illustrates the effect of inorganic fillers on the smoke production from thermosetting materials. Here the vertical mode was used because the materials remained in the holder for the duration of the test. Basically, the filler effect is to dilute the amount of resin for a given volume of sample. Calcium carbonate, however, appears to show an additional effect in the halogenized polyester systems by acting as a scavenger for HCl and HBr, while the water vapor from the alumina hydrate combines with the HCl and HBr to form halogen acid aerosols which contribute to light attenuation. It is suggested that water vapor from the alumina hydrate combines with the carbon particles formed to yield CO and thereby decreases the amount of carbonaceous smoke [9].

Other materials, however, cannot be tested vertically with adequate reproducibility due to the problem of melting and dripping. As an example, figure 8 shows the results from several flexible polyurethane foams containing smoke suppressants. When tested in the vertical mode they could not be differentiated because the variability masked the effect of the additive. The horizontal data indicated that the smoke suppressants could decrease light obscuration by as much as 10% during the early stages of burning, and actually contributed more smoke than the no additive sample during the latter stages.

Table 1. Comparison of Vertical and Horizontal Smoke Density Values in the Flaming Mode*

	Smoke, D_m (Average of 3) Horizontal	Vertical
Thermoplastic:		
Polypropylene	398	57
Polyethylene	286	35
Nylon 6,6	264	48
Paraffin Wax	228	83
Non-thermoplastic:		
Phenolic impregnated paper	155	140
Vulcanized fiber	52	63
Elm (0.4 cm thick)	59	57
Balsa Wood	16	8

*Materials, except elm, were tested in 0.15 cm thickness.

Table 2. Repeatability
(Polystyrene, 7.6 x 7.6 x .008 cm, 4 grams)

D_m, Vertical	D_m, Horizontal
221	421
163	449
233	423
226	446
253	393
231	421
236	421
223	422
$\bar{x}$ = 223	$\bar{x}$ = 425
σ = 11.8%	σ = 4.1%

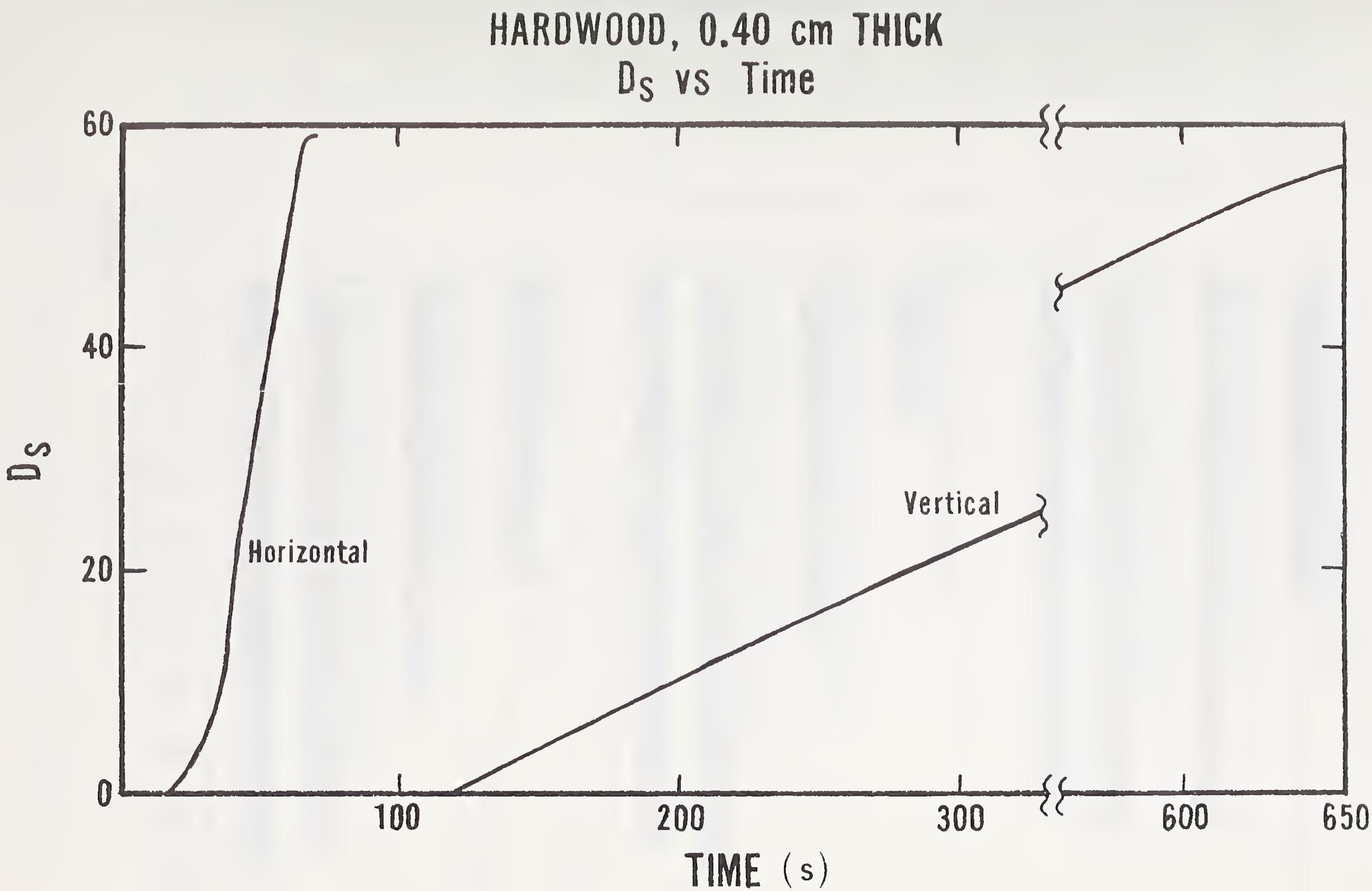


Figure 6. Burning Rates

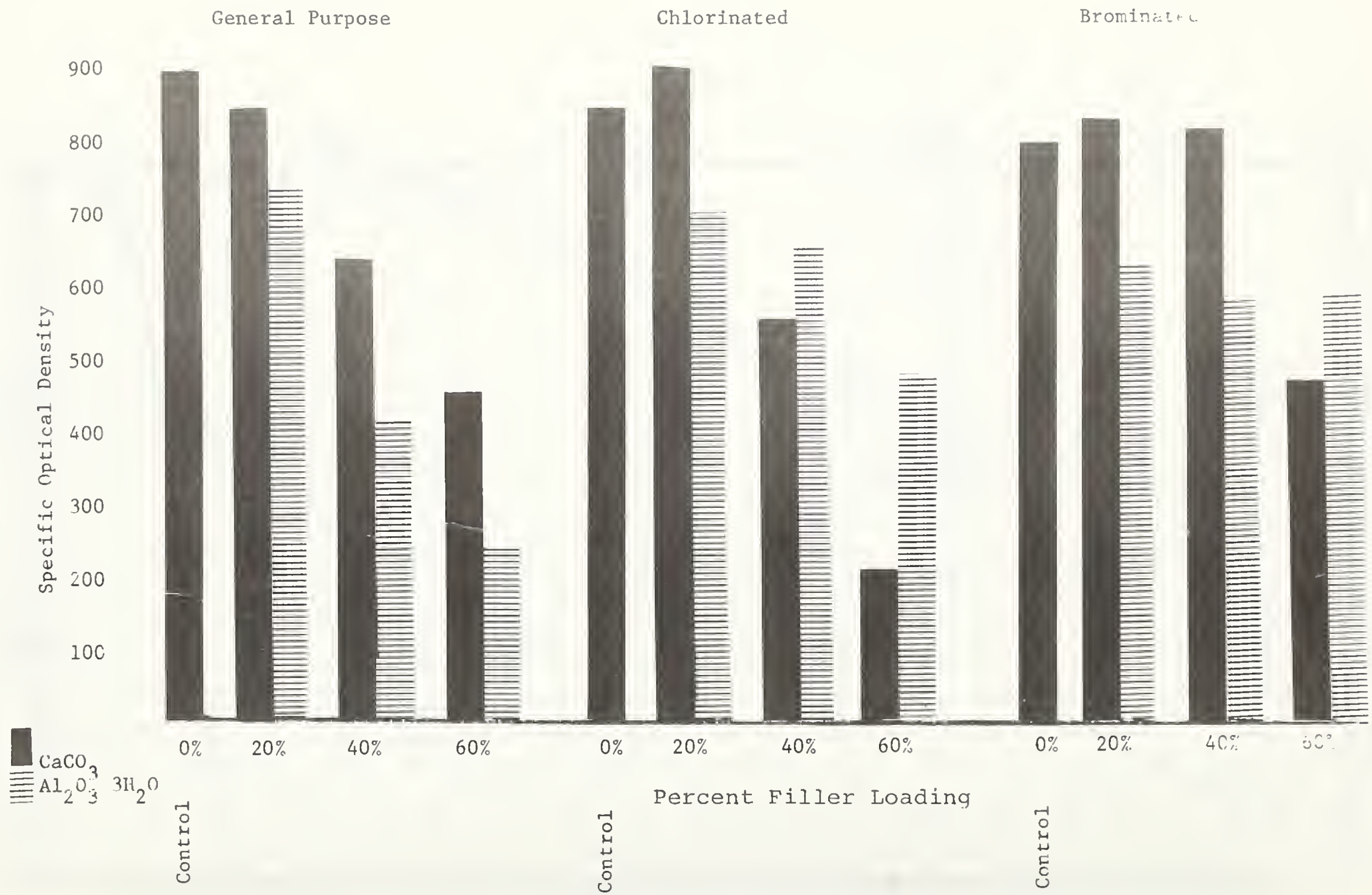


Figure 7. Evaluation of Smoke Suppressants to Polyester Systems

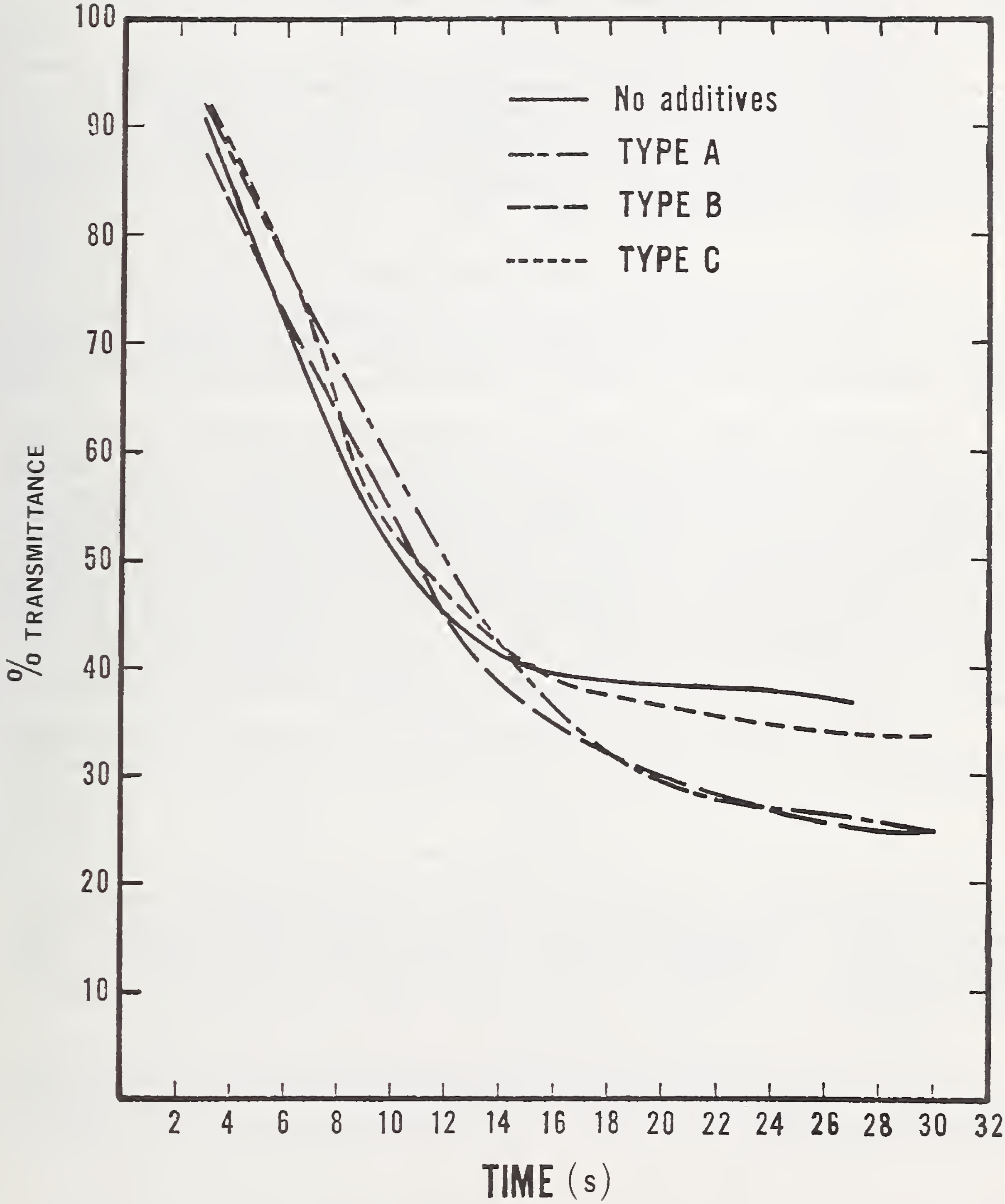


Figure 8. Smoke Suppressants for Flexible Polyurethane

3.3. Effect of Material Combinations

Layered products such as carpeting can be evaluated in the horizontal mode. The horizontal sample configuration appears especially appropriate for items normally used as floor coverings. Table 3 shows data from four representative carpets and three underlayments tested singly and in combination under the flaming exposure mode. Specimens were 2.5 x 2.5 cm in order to avoid saturation of the photometric system.

It is interesting to note the role of underlayments in the total smoke produced by carpet/underlayment combinations. The smoke production of a carpet system can be drastically altered by the choice of underlayment. Table 3 illustrates the effect of underlayment on the total smoke produced from several carpet/underlayment combinations. This data, however, applies only to these specific samples and should not be extrapolated to other carpets made from the same generic fiber types.

3.4. Mass Optical Density

Mass optical density can be related to chemical structure, as shown in table 4. This data was obtained from 7.6 x 7.6 x 0.15 cm samples. Comparisons were therefore made on the basis of mass loss from equal initial volumes. Equal volumes would be the method for substituting these materials in products.

The polymers listed contain singly bonded carbon backbones. The only differences occur in the pendant groups. Polystyrene, with a pendant phenyl group, exhibits the highest MOD. Styrene monomer is somewhat lower, perhaps indicative of the effect of molecular weight or vaporization rate on smoke characteristics. If the phenyl group is replaced by a methyl, one obtains polypropylene, with significantly less smoke than polystyrene. If, in turn, the methyl is replaced by chlorine, the resultant polyvinylchloride shows a further smoke decrease. It should be noted that the chlorine does contribute significantly to particulate formation on an equal weight loss basis. The MOD of polyvinylchloride is higher than that of polyethylene, where the chlorine is replaced by hydrogen. This may be due to the formation of HCl aerosol. Paraffin wax chemically is a low molecular weight polyethylene, and again its somewhat lower MOD may reflect the effect of molecular weight.

Finally, polyoxymethylene was included to indicate what happens if the carbon linking is totally absent. Essentially no light obscuring smoke is produced.

4. CONCLUSION

The development of a horizontal sample mounting method for the Smoke Density Chamber is an evolution of the method to provide better data for an extended range of synthetic materials currently finding applications in consumer products. In addition, the mass optical density holds promise in the area of fundamental studies and would extend smoke measurements to powders and liquids.

The vertical mounting is appropriate for materials that remain intact during the course of the test or for applications requiring data from a vertical product configuration. The vertical and horizontal sample orientation, while yielding smoke values which are not always comparable, can be used to complement each other.

Table 3. Carpets and Underlayments
(D_m, Horizontal Flaming Exposure)

Carpet* / Under-layment		Wool**	Nylon	Acrylic	Polyester
		536	540	606	1,006
Hair Jute	151	642	645	809	928
Rebonded Urethane	362	765	770	902	1,058
SBR Waffle	909	1,038	1,042	1,312	1,402

*Average of three test results

**See table 3a (below) for carpet descriptions

Table 3a. Carpet Description

Fiber	Type	Construction	Face Weight (oz/yd^2)
Nylon	Level Loop	Tufted	28
Wool	Plush	Tufted	43
Acrylic	Level Loop	Tufted	42
Poly-ester	Shag	Tufted	45

Table 4. Structure and Mass Optical Density

Material		MOD (cm^2/g)
Polystyrene	$(CH—CH_2)n$ | 	14,300
Styrene	$CH = CH_2$ | 	9,600
Polypropylene	$(CH—CH_2)n$ | CH_3	5,250
PVC	$(CH-CH_2)n$ | Cl	3,400
Polyethylene	$(CH—CH_2)n$ | H	2,800
Paraffin Wax	$(CH—CH_2) < n$ | H	2,300
Polyoxymethylene	$(CH_2—O)\ n$	$\sim n$

5. ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Robin McCoy and Michael Bitzel for their efforts in the experimental phase and Thomas Lee for his advice and heat flux measurements.

6. REFERENCES

[1] Harrison, G. A. and Houser, J. L., A Survey for the Collection of Professional Opinion on Selected Fire Protection Engineering Topics Fire Journal, Vol. 69, No. 2 (March 1975).

[2] Operation School Burning No. 2., NFPA Report Conducted by Los Angeles Fire Department (1961).

[3] Auticu, J., Toxicology Aspects of Flammability and Combustion of Polymeric Materials, J. Fire and Flamm. (July 1970).

[4] Jin, T., Visibility Through Fire Smoke, Report of Fire Research Institute of Japan, No. 33 (1971).

[5] ASTM E-84-70, Standard Method of Test for Surface Burning Characteristics of Building Materials, Part 18 (1974).

[6] Standard Test Method for Measuring the Smoke Generated by Solid Materials, National Fire Protection Association, NFPA 258-T (1974).

[7] King, T., Smoke and Carbon Monoxide Generation from Burning Selected Plastics and Red Oak, Fire Safety Research, Proceedings of a Symposium held at the National Bureau of Standards on August 22, 1973, Nat. Bur. Stand. (U.S.), Special Publication 411 (Nov. 1974).

[8] Lee, T. G. Interlaboratory Evaluation of the Smoke Density Chamber, Nat. Bur. Stand. (U.S.), Technical Note 708 (Dec. 1971).

[9] Seader, J. D. and Chien, W. P., J. Fire and Flamm., Vol. 5, 151-163 (April 1974).

[10] Lawson, D. F., Kay, E. L. and Roberts, D. T., Rubber Chemistry and Technology, Vol. 28, 124-131 (April 1975).

APPENDIX

Table A1. Horizontal Configuration

Component A: Sample Holder with Load Cell
Bill of Materials

Item	Description	Quantity
1	3" x 3" x 3/16" Cement-Asbestos Board	1
2	6-32 x 3/8" Flat Head Screw, Stainless Steel	2
3	1" diameter x 1/2" Machinable Ceramic	1
4	3-1/16" x 3-1/16" x 1/8" Plate, Stainless Steel	1
5	1-1/4" x 1/2" x 1/8" Plate, Stainless Steel	2
6	Component C	1
7	10-32 x .30" Fillister Head Screw, Stainless Steel	4
8	Load Cell 1 lb.	1
9	3-1/4" x 3-1/4" x 5/16" Plate, Brass	1
10	3" diameter x 2-3/4" Brass Tubing, .065" wall thickness	1
11	1-1/2" diameter x 2-3/4" Copper Tubing, .065" wall thickness	1
12	Load Cell Transducer	1
13	3/16" diameter x 3/4" Brass Tubing, .065" wall thickness	2
14	3-1/4" x 3-1/4" x 1/4" Brass Plate	1

Table A2. Horizontal Configuration

Component B: Sample Holder without Load Cell
Bill of Materials

Item	Description	Quantity
1	6-32 x 1/2" Flat Head Screw, Stainless Steel	8
2	3-3/16" x 3-3/16" x 1/8" Plate, Stainless Steel	1
3	1-1/4" x 1/2" x 1/8" Plate, Stainless Steel	2
4	1/4" Diameter x 2-3/4" Round Stock, Stainless Steel	4
5	3-7/32" x 3-7/32" x 1/8" Stainless Steel Plate	1

Table A3. Horizontal Configuration

Component C: Cooling Jacket for Load Cell
Bill of Materials

Item	Description	Quantity
1	3-7/16" x 3-7/16" x 3/16" Plate, Brass	1
2	3-7/16" x 3-7/16" x 3/16" Plate, Brass	1
3	1/4" Diameter x 1" Brass Tubing, .065" wall thickness	1
4	3/16" Diameter x 1" Brass Tubing, .065" wall thickness	1
5	3-7/16" x 2-7/8" x 1" Plate, Brass	1
6	6-32 x 13/32" Socket Head Screw	11
7	4-40 x 3/8" Socket Head Screw	4

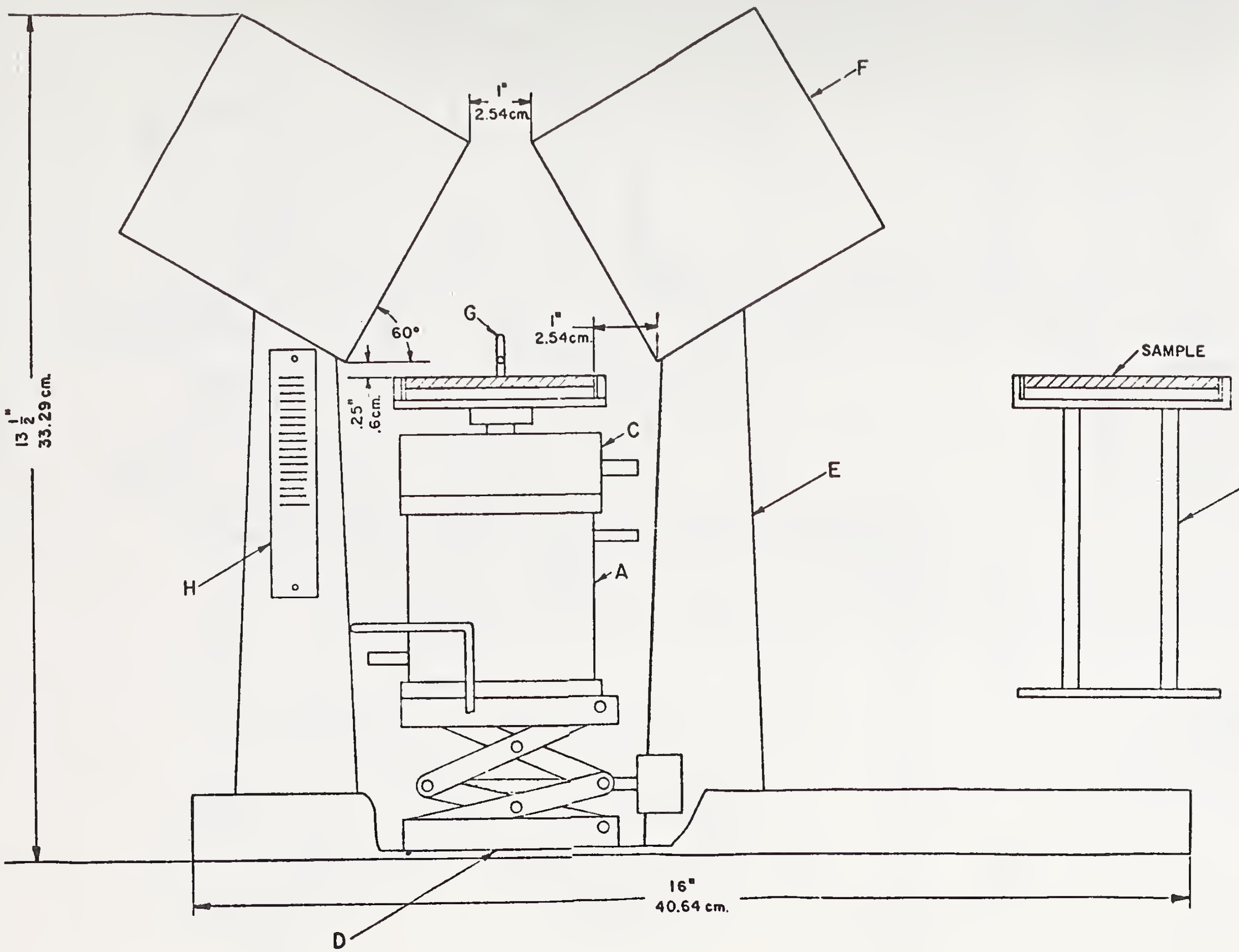
Component D: Lab Jack

Component E: Furnace Assembly

Component F: Furnace

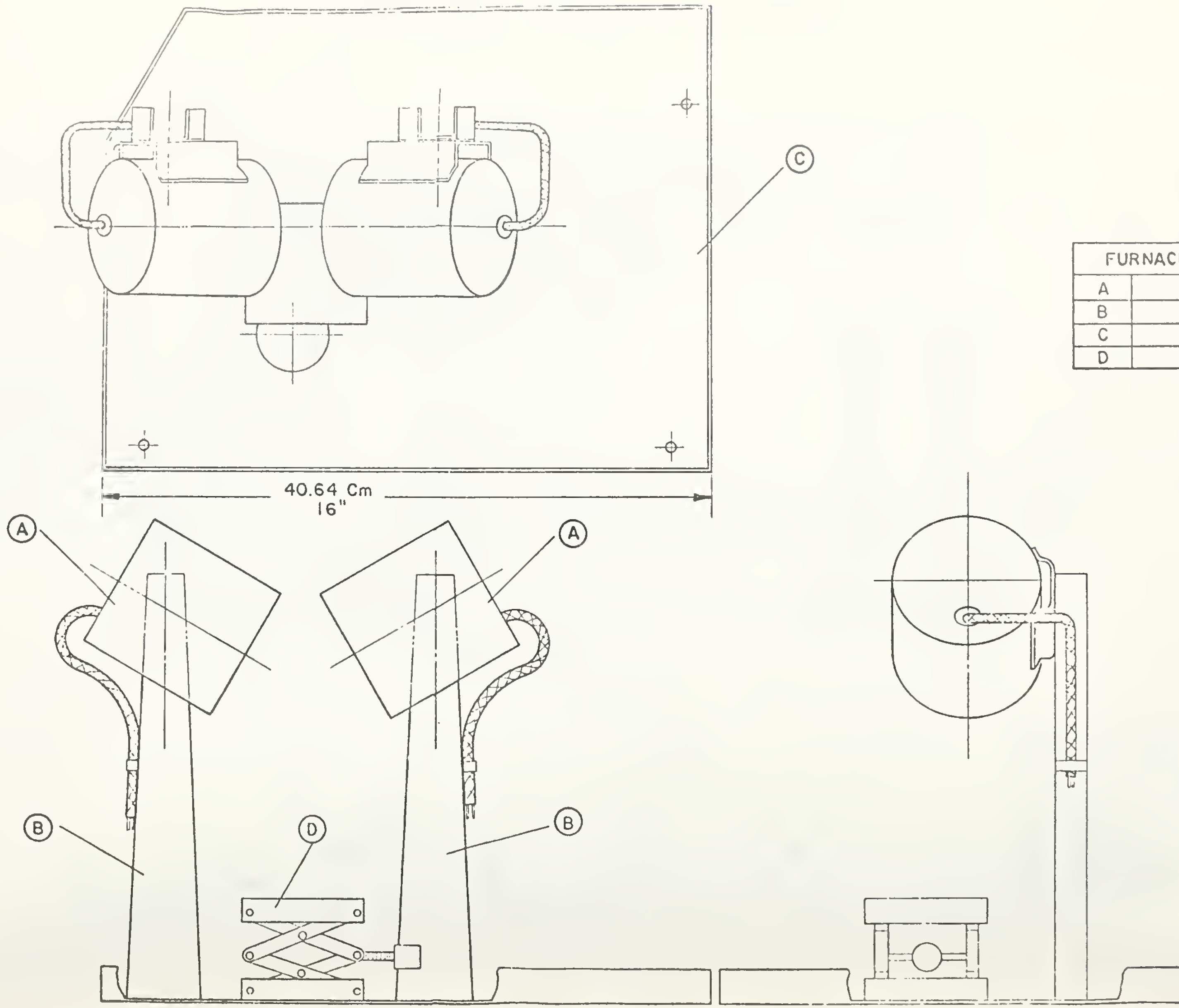
Component G: Pilot Flame (Stainless Steel Tubing, 1/16" inside diameter)

Component H: Sample Height Adjustment (4" x 3/4" x 1/8" Stainless Steel)



A	SAMPLE HOLDER & LOAD CELL
B	SAMPLE HOLDER
C	COOLING JACKET
D	LABORATORY JACK
E	FURNACE ASSEMBLY
F	FURNACE
G	PILOT FLAME
H	SAMPLE HEIGHT ADJUSTMENT

Figure A1. Horizontal Configuration



FURNACE ASSEMBLY	
A	FURNACE
B	FURNACE SUPPORTS
C	BASE
D	JACK

Figure A2. Horizontal Configuration

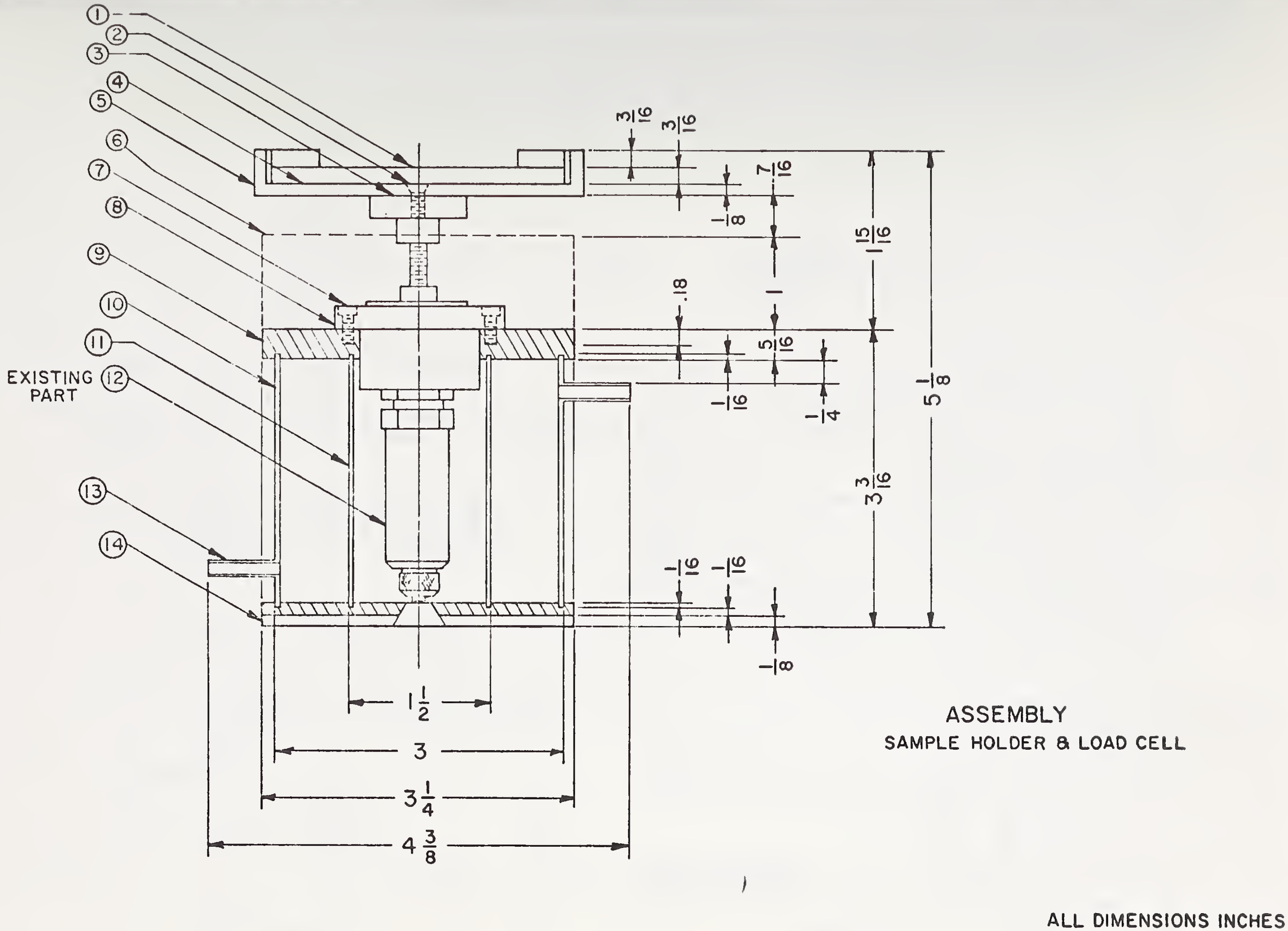


Figure A3. Assembly Sample Holder and Load Cell

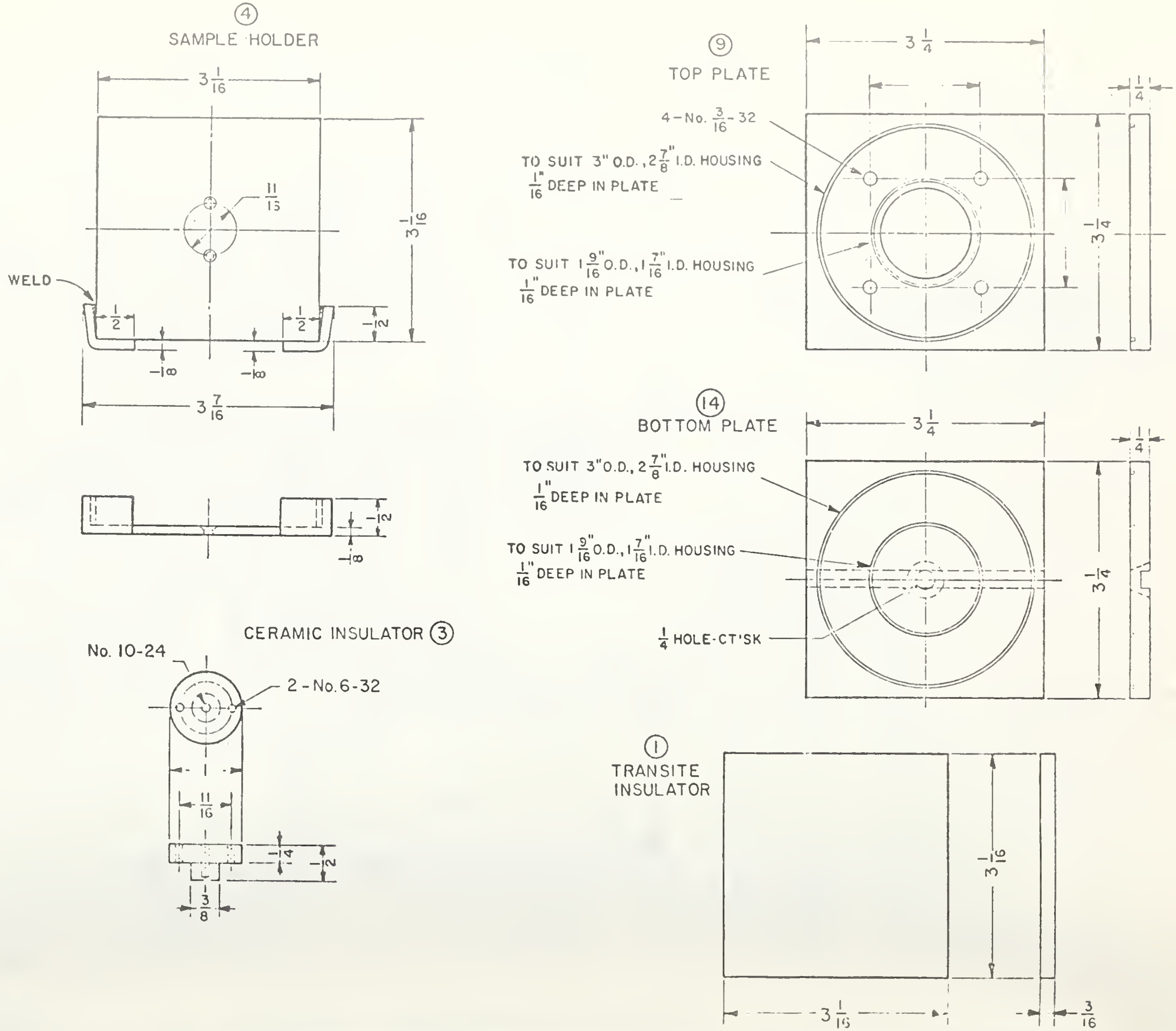


Figure A4. Sample Holder

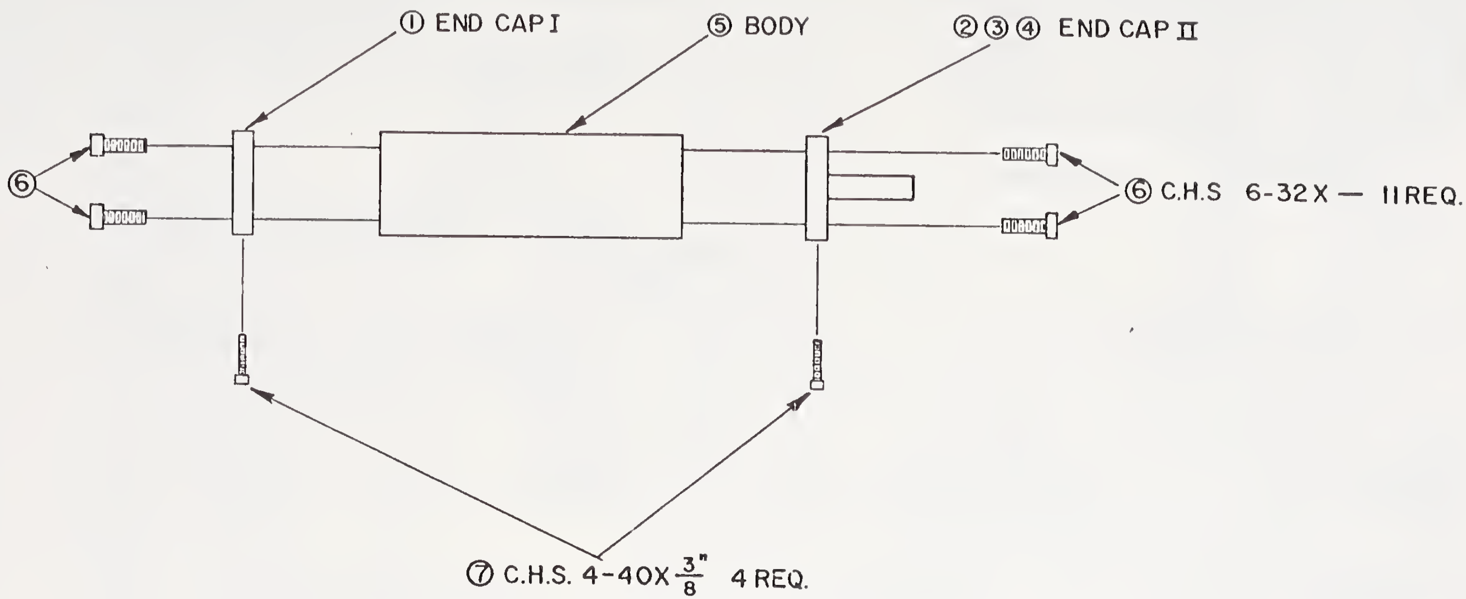


Figure A5. Cooling Jacket Assembly

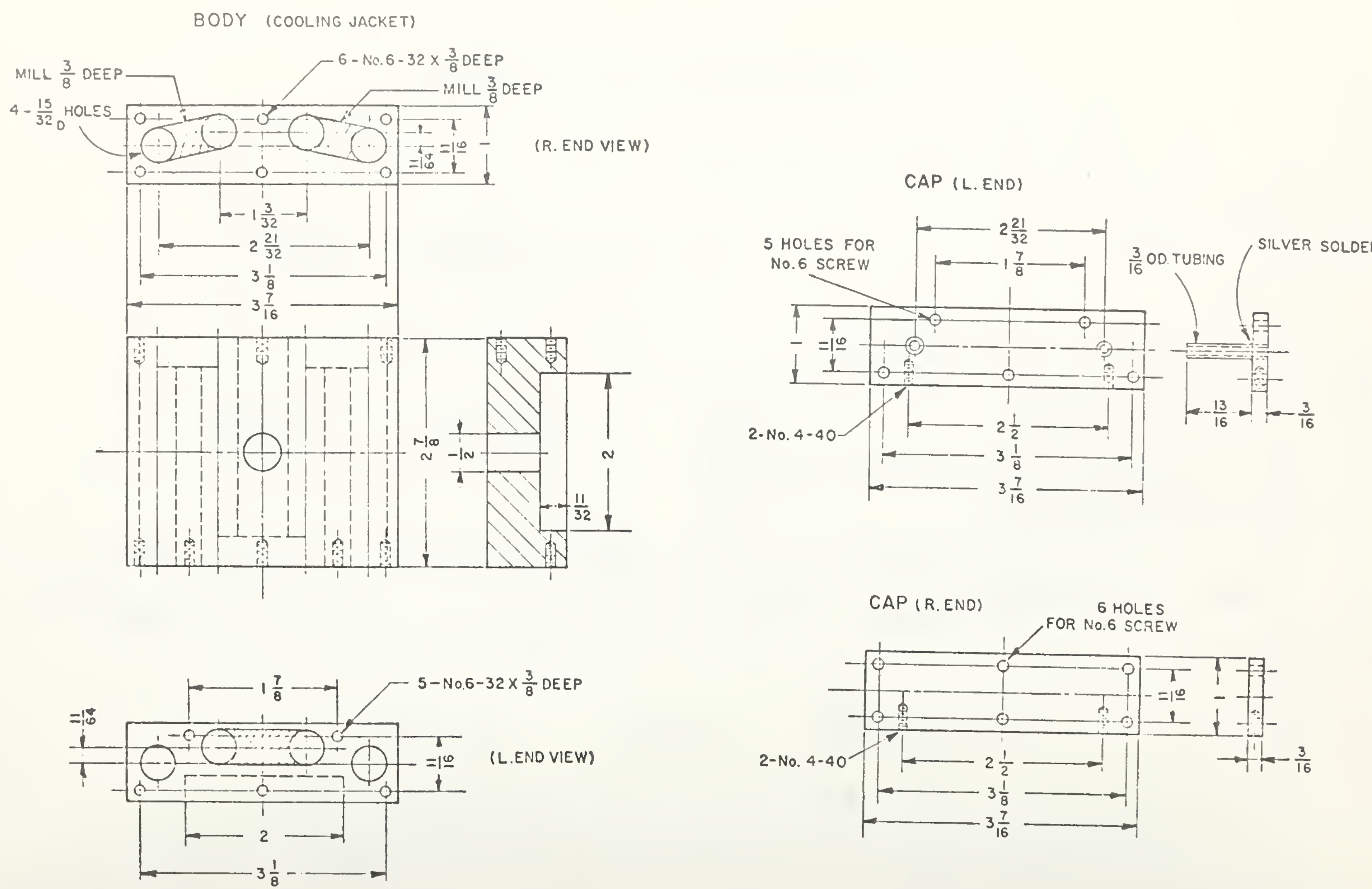


Figure A6. Cooling Jacket

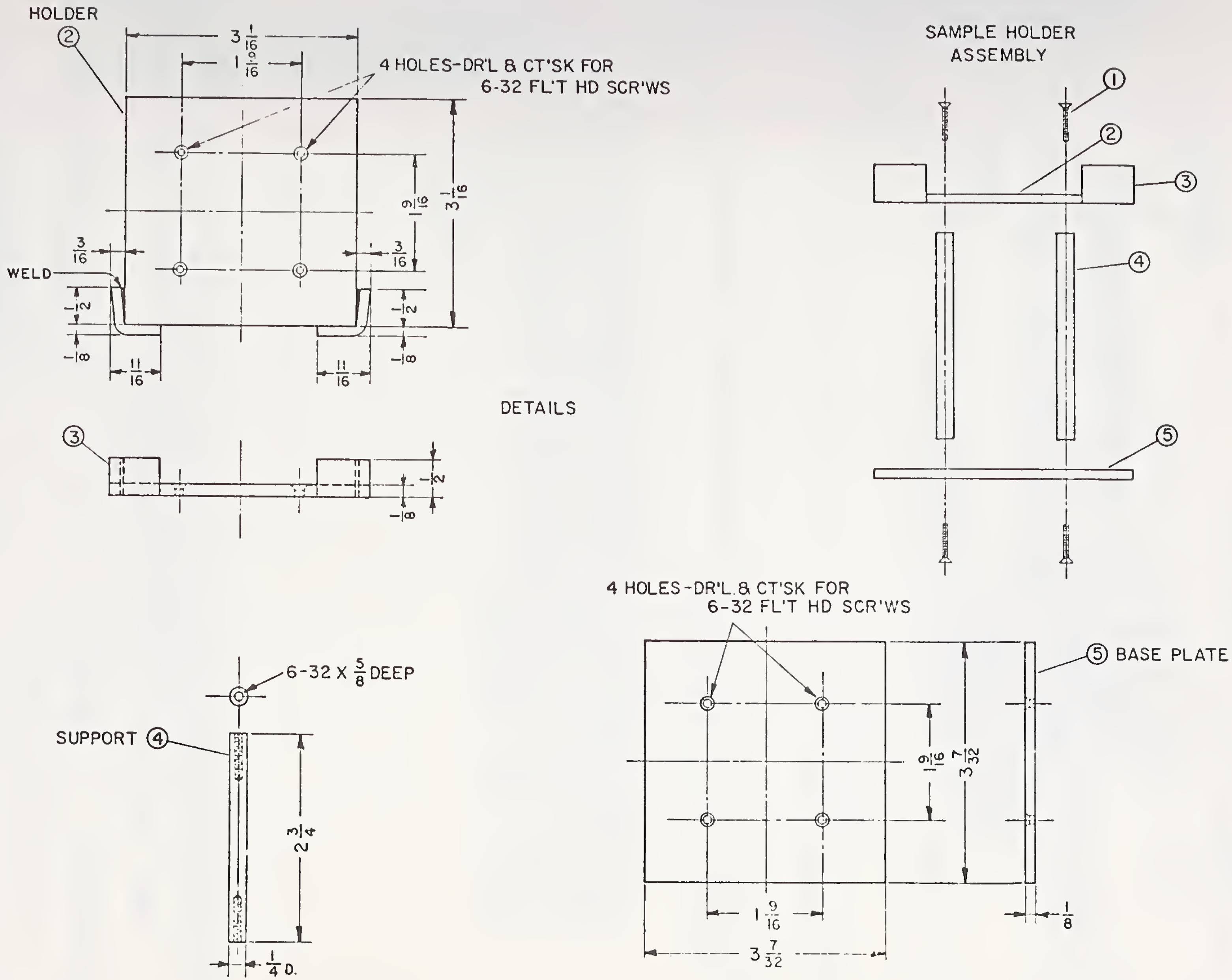


Figure A7. Sample Holder with Load Cell Spacer

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Smoke measurements were compared for various materials in the vertical and horizontal positions. There appeared a significant difference for thermoplastic materials because of the melting away from the incident heat flux in the vertical position. The horizontal mode in addition allows one to relate the chemistry of polymeric materials to the amount of smoke production. Finally, smoke measurements are made of products containing various amounts of smoke suppressants.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Fire performance; horizontal and vertical smoke measurements; smoke; smoke density chamber; smoke suppressants.

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