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Smoke Production of Nonmetallic Pipes



William H. McLain
and
Louis Nash



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U.S. Coast Guard
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G. T. Gunther
Technical Director, Acting
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

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16. Abstract <p>The smoke production of nonmetallic pipes was investigated using "Test Method for Specific Optical Density of Smoke Generated by Solid Materials," ASTM E 662. The pipe samples consisted of two epoxy resin glass reinforced pipes, two vinyl ester resin glass reinforced pipes, a PVC pipe, and a phenolic resin glass reinforced pipe.</p> <p>The use of flat test specimens of pipe material was deemed to be impractical due to the difficulty of obtaining specially made specimens and the probability of altering the resin to glass ratio. The tensioning of the filaments during manufacturing may result in a significant difference in the resin/fiberglass ratios at the pipe surface as compared to flat stock production. A Code of Practice was developed for preparing and mounting the pipe specimen to permit the use of curved surfaces in ASTM E 662. The pipe specimens were prepared by cutting pipes to provide a curved surface area equal to the area of a flat test specimen. The space behind the pipe specimen was left void to simulate a dry pipe.</p> <p>The Code of Practice permitted the specific optical density (Dm) to be determined for nonmetallic pipes. Dm ranged from 2 to 209 for nonflaming exposures and from 16 to 563 for flaming exposures. The phenolic pipe produced the least amount of smoke.</p> <p>The effect of orientation of test specimen in the sample holder was investigated using PVC and phenolic pipe. The two orientations were horizontally run pipes and vertically run pipes. For PVC pipe in the flaming exposure, the Dm was higher when the pipe was vertically run than when horizontally run. For PVC pipe in the nonflaming exposure and phenolic pipe in both exposures, the effect of orientation is minimal.</p> <p>The effect of pipe diameter was investigated using PVC pipe. The Dm was less for 6-inch diameter PVC pipe than for 2-inch and 4-inch PVC pipe. This was not attributable to differences in mass loss. As the mechanism for the difference in Dm is unknown, no conclusion is possible on whether it is possible to limit testing to certain diameters of pipes.</p> <p style="text-align: center;">DTIC QUALITY INSPECTED 8</p>					
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METRIC CONVERSION FACTORS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (WEIGHT)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (EXACT)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
acres	acres	0.4	hectares	ha
MASS (WEIGHT)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (EXACT)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 (exactly).

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1.0 INTRODUCTION

The International Maritime Organization is developing guidelines for the usage of nonmetallic pipes aboard ships. The maritime industry is interested in nonmetallic pipes due to the expense and the rusting of steel pipes. The proposed guidelines address such items as fire endurance and smoke production. The test for smoke production is "Test Method for Specific Optical Density of Smoke Generated by Solid Materials," ASTM E 662.¹ This report addresses three phases of testing relating to the application of ASTM E 662 to nonmetallic pipes. The cumulation of the three phases is a draft protocol for preparing pipe samples for ASTM E 662.

This work was conducted at the request of the Marine Technical and Hazardous Materials Division and the Merchant Vessel Inspection and Documentation Division of the Office of Marine Safety, Security and Environmental Protection.

1.1 International Maritime Organization

The International Maritime Organization (IMO) is an agency of the United Nations. IMO's purpose is to develop standards to improve safety at sea and prevent pollution of the oceans. It was established in 1958 under the name of the Intergovernmental Maritime Consultative Organization (IMCO). The name was changed in 1982.²

IMO's governing body is an assembly of representatives from 134 member countries and 2 associative members. The assembly is supported by five committees, one of which is the Maritime Safety Committee. It is supported by ten technical subcommittees; one of which is the Sub-Committee on Fire Protection.³ Each subcommittee sets up working groups to address specific issues at each session.

The U.S. Coast Guard represents the United States at meetings of the Maritime Safety Committee and its subcommittees. The U.S. delegate to the Sub-Committee on Fire Protection is the chief of the Fire Protection Section, Ship Design Branch of the Marine Technical and Hazardous Materials Division.

¹ ASTM stands for the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

² For an overview of IMO and the involvement of the U.S. Coast Guard and industry in IMO, see Thompson (1990)

³ IMO uses the English practices of the English language, hence Sub-Committee.

IMO's principle standard for life safety is the International Convention For The Safety Of Life At Sea, 1974 (1974 SOLAS). It addresses such items as vessel stability, life boats, machinery and electrical installations, communications, and navigation. Chapter II-2 addresses fire protection requirements. Major amendments to the 1974 SOLAS were adopted in 1981 and 1983. Other amendments have been or are pending adoption.

1.2 Background on Smoke from Pipes

In its 33rd session, the Sub-Committee on Fire Protection agreed that ASTM E 662 is a suitable basis for an IMO standard for smoke from pipes.⁴ At that point, the Sub-Committee was attempting to determine appropriate acceptance criteria.

Regulations 34.7 and 49.2 of Chapter II-2 of 1974 SOLAS as amended require that interior surfaces do not produce excessive quantities of smoke. This has been interpreted to include nonmetallic pipes (Sub-Committee on Fire Protection 1990a). In its 35th session, the Sub-Committee restated its agreement that ASTM E 662 is a suitable basis for an IMO standard for smoke. The Sub-Committee also considered changes to the ASTM E 662 test protocol needed to apply this test method to nonmetallic pipes.⁵

It is anticipated that most nonmetallic pipes will require fireproofing to meet the higher levels of fire endurance.⁶ The use of fireproofing would enable a wider group of materials to be used for nonmetal pipes provided the fireproofing meets flame spread and smoke criteria.

2.0 OBJECTIVE

The testing was conducted in support of developing the U.S. position at IMO. At each IMO meeting, some issues were resolved and others raised. Other countries were also conducting research which affected the direction of the effort. This resulted in two phases of testing which were not planned in advance as a single piece of work. The constraints of time and funds resulted in mixed success in meeting the objectives of each phase. No effort was made to readdress an objective as the decisions made at IMO resulted in different objectives.

The objective of the first phase was to determine what level of smoke production one could expect from pipes when tested to ASTM E 662.

⁴ Sub-Committee on Fire Protection 1988, para. 3.9

⁵ Sub-Committee on Fire Protection 1990b, para. 3.22 and 8.5

⁶ Sub-Committee on Fire Protection 1990a, para. 18

The objectives of the second phase were to investigate the effects of sample orientation and pipe size on the results from ASTM E 662.

The objective of the third phase was to develop a Code of Practice for testing nonmetallic pipe using the ASTM E 662 test procedure. This Code was to include the possibility of testing pipes with fireproofing.

3.0 PHASE 1

3.1 Technical Approach

3.1.1 Test Protocol

A modified ASTM E 662-83 test protocol was used to determine the quantity of smoke produced by plastic pipe materials. All tests were made with a Model 40580060 "Smoke Density Chamber" manufactured by the American Instrument Company. To determine the smoke density, this test measures the attenuation of a light beam by smoke accumulating in a closed chamber due to nonflaming and flaming combustion. The fire load imposed on the test sample is generated by the heat flux from an electric furnace.

Prior to the start of the tests, the operation of the equipment and laboratory procedures were verified by determining smoke obscuration values for standard reference materials subjected to flaming and nonflaming exposures. All test samples were conditioned for a minimum of 24 hours at $50 \pm 5\%$ relative humidity and $23 \pm 3^\circ\text{C}$.

The test protocol requires that the test specimen be representative of the materials tested. The protocol also states that the test method is sensitive to small variations in sample geometry, therefore specimens are required to be flat.⁷ Unfortunately, these requirements are mutually exclusive for fiberglass reinforced plastic pipes. The tensioning of the filaments during manufacturing may result in a significant difference in the resin/fiberglass ratios at the pipe surface as compared to those characteristic of flat stock production.

Therefore, modifications were made to the test protocol for testing of pipes. These modifications are explained in the following Code of Practice. Briefly, the sample mounting procedure was modified to adapt the test for use with curved surfaces (Figure 1). This method of mounting ensures impingement of flames onto the test specimen during flaming exposure tests. The curved test specimens were prepared by cutting pipes to provide a curved surface area equal to that of a flat test specimen.

⁷ Sub-Committee on Fire Protection 1988, para. 6.3.1 and 3.2

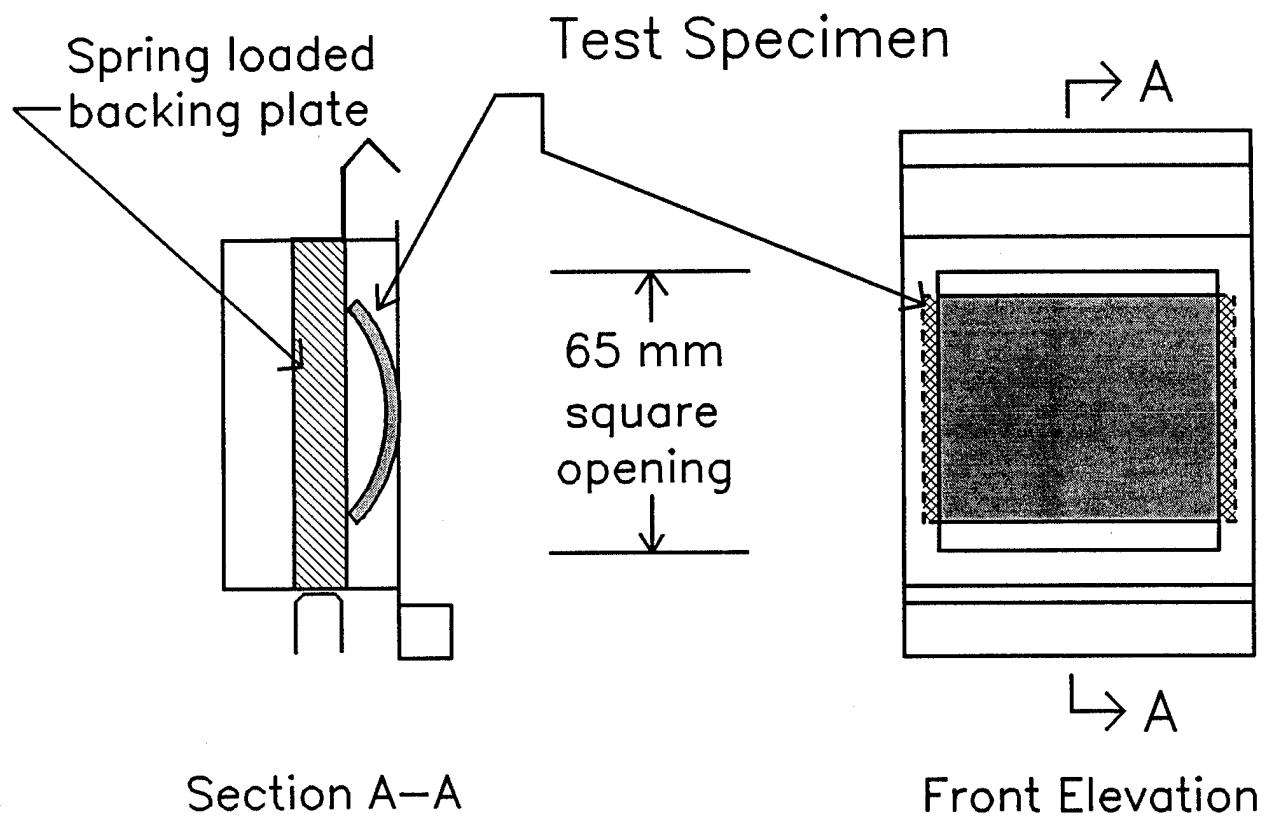


Figure 1.

ASTM E 662 Specimen Holder with Pipe Section Specimen

Code of Practice

1. The test sample shall be equivalent in exposed surface area to a flat surface 76 mm by 76 mm.

Rationale: The equivalent area is defined as the exposed surface of a normal flat surface. For a 76 mm x 76 mm test sample, this area is 57.76 cm². Because of the curvature of a pipe wall, a sample covering the normal exposed area of the sample holder would expose a larger surface area. Since the smoke produced is proportional to the total exposed area, higher smoke values would be expected. The equivalent area is therefore defined as an exposed curved surface of 57.76 cm².

2. The samples will be mounted on calcium silicate board.

Rationale: Standard practice is to use calcium silicate board as a substitute for asbestos cement board due to the concerns with asbestos. This also maintains some consistency with the methodology used in IMO testing for flame spread.

3. The test samples will be fabricated by cutting pipe lengthwise into individual sections and then assembling the sections into a test sample as representative as possible of a flat surface.

Rationale: The test method was developed for use on flat surfaces. The pass/fail criteria are based on experience gained with flat surfaces. The pipes are sectioned lengthwise in order to reduce the effect of curved pipe surfaces on the production of smoke. The principal concern with the curved surface is the change in incident heat flux on the sample. The flux from the heating coil varies as a function of distance. The use of a quasi-flat surface avoids the need for the development of a correction factor or alternative pass/fail criteria, either of which would complicate the use of the test procedure for both regulators and manufacturers.

4. All cuts will be made normal to the pipe wall.

Rationale: Cutting the pipe perpendicular to the pipe wall provides a uniform sample thickness. Other modes of cutting would result in a variable thickness and in some cases expose the interior of the pipe wall. The walls of fiberglass pipes are constructed of layers; the thermal and chemical properties may vary with the layers. Changing the respective ratios of the various layers could result in an unrepresentative quantity of smoke being produced.

5. The test samples will be mounted such that the sample uses the entire horizontal extent of the sample holder (See Figure 1).

Rationale: Other than for the sake of consistency, this requirement is necessary for the flaming exposure. The flame jets used in a flaming exposure extend from the left side to the right side of the sample holder. Testing with an equivalent surface area results in the sample not filling the entire area of the sample holder. The unfilled or bare area increases as the pipe diameter decreases. If the pipe sample is mounted to use the entire vertical extent of the sample holder, the left and right sides of the face of the sample holder is bare. As a result, the flames and heat from the outboard flame jets may not impinge on the sample. Mounting the sample horizontally in the sample holder exposes the sample to the heat from all of the flame jets. This provides a fire exposure more consistent with that of a flat test sample.

6. The highest part of the exposed surface will pass through the center of the test sample holder.

Rationale: This requirement ensures that the sample will be exposed to the highest heat flux. Any flaming is likely to impinge on the center of a horizontally mounted test specimen.

7. The individual pipe sections will be mounted so that the highest part of the exposed surface of the curved test specimen is in the same plane as the surface of a flat test sample (See Figure 1).

Rationale: The flux from the heating coil varies as a function of distance. The part of the curved surface above the normal location of the backing board is closer to the heating source and receives a higher heat flux. For a sample mounted below the normal location, the heat flux is less.

8. The space between the concave unexposed surface of the test sample and the surface of the calcium silicate backing board will be void.

Rationale: The void space simulates a dry pipe configuration. In a dry pipe there is no liquid to transfer the heat away from the inner pipe wall. Therefore the decomposition responsible for the production of smoke occurs more rapidly. By leaving the space void, rather than back filling with an insulating wool packing, the convective heat flux in a dry pipe may be simulated.

9. The space between the top of the exposed test surface and the bottom edge of the sample holder frame, where the pipe extends under the frame, will be filled with a high temperature insulating wool.

Rationale: Unlike a flat surface, the lip of the test holder does not protect the edges of a curved sample from the incident radiant heat flux. This results in greater surface area for exposure and increases the quantity of smoke produced. Shielding this additional surface area with a high temperature insulating wool provides a fixed area of exposure. This provides a more consistent basis for comparing flat and curved materials.

10. The test samples will be held in place by the edges of the test frame and, if necessary, by wire (#18 gage nichrome recommended).

Rationale: In most cases, the lip of the test sample holder will hold the test sample in place. If the sample sags, wire may be necessary to hold the test sample in place. This is likely in the case of thermoplastic materials undergoing flaming exposure tests. Eighteen gage nichrome wire is adequate for this purpose when the calcium silicate backing is drilled and the wire is tied on the back side of the backing.

3.1.2 Materials/Constructions

This project determined the quantity of smoke produced by representative samples of six materials being considered for use on ships. The materials were taken from production piping and were chosen to represent typical materials that are commercially available rather than specific manufacturers' products.

The materials tested were polyvinyl chloride pipe and, fiberglass reinforced phenolic, polyester, and epoxy resin pipes. The type of material and manufacturer for each pipe is listed in Table 1. Manufacturer's specifications and laboratory measurements for these materials are listed Appendix A.

With one exception of a flat test specimen cut from an 11-inch flange, the test specimens were fabricated from 2-inch standard production piping. The pipes were cut to form an exposure area equivalent to a flat test sample. The exact size was 76 mm along the length of the pipe and a circumferential surface length of 76 mm. The volume between the backside of the exposed surface and the backing plate was left open. The pipes were held in the holder by a 13 mm Marinite backing plate and a spring. Aluminum foil was wrapped to seal the joint between the Marinite and the test holder. The edges of the test specimen, that would have been under the lip of the test holder if the specimen were flat, were also covered with aluminum foil.

TABLE 1. LIST OF MATERIALS FOR NONMETAL PIPES			
LAB MARK	MATERIAL TYPE	MANUFACTURER	PRODUCT NAME
M80	Epoxy Resin Glass Reinforced	Smith Fiberglass	Greenthread
M81	Polyvinyl Chloride	Charlotte	--
M82	Phenolic Resin Glass Reinforced	Ametek	Chemtite
M83	Epoxy Resin Glass Reinforced	Ameron	Bondstrand 2000M
M84	Vinyl Ester Resin Glass Reinforced	Smith Fiberglass	Polythread
M85*	Epoxy Resin Glass Reinforced	Ameron	Bondstrand 7000M

* Sample was cut from an 11-inch flange.

3.2 Test Results

A minimum of three tests were made for each fire exposure. The laboratory data sheets for each test are in Appendix B. These data are summarized in Tables 2 through 4. Tables 2 and 3 lists specific optical density, D_m , values for nonflaming and flaming fire exposures.⁸ For nonflaming exposures, the average values range from 2 to 209. For flaming exposures, the average values range from 16 to 563. Tables 4 and 5 lists the percent weight lost during the test. For nonflaming exposure, the average values range from 6 to 7 percent with one exception; the polyvinyl chloride pipe specimen lost 30 percent of its weight. For flaming exposures, these values range from 13 to 55 percent.

⁸ ASTM E 662-83 specifies that the corrected specific optical density (D_m cor) be reported. In this report, the specific optical density (D_m) without correction is reported to conform with the practice of later versions of ASTM E 662.

TABLE 2. SPECIFIC OPTICAL DENSITY, Dm, FOR NONFLAMING EXPOSURE

Pipe Material (Lab Mark)	Dm by Sample Number						Average Dm
	S1	S2	S3	S4	S5	S6	
GR Epoxy (M80) ¹	122	122	165	---	---	---	136
Polyvinyl Chloride (M81)	84 ²	187	201	---	146	182	179
GR Phenolic (M82)	2	1	2	---	---	---	2
GR Epoxy (M83)	221	197	186	---	---	---	201
GR Vinyl Ester (M84)	359 ²	35	43	43	40	---	40
GR Epoxy (M85)	173	199	254	---	---	---	209

¹ GR stands for glass reinforced.

² Data was not included in the average.

TABLE 3. SPECIFIC OPTICAL DENSITY, Dm, FOR FLAMING EXPOSURE

Pipe Material (Lab Mark)	Dm by Sample Number					Average Dm
	S4	S5	S6	S7	S8	
GR Epoxy (M80) ¹	545	548	---	396	---	496
Polyvinyl Chloride (M81)	353	---	---	300	333	329
GR Phenolic (M82)	15	18	16	---	---	16
GR Epoxy (M83)	>528 ²	456	621	---	---	>535
GR Vinyl Ester (M83)	---	---	528	582	578	563
GR Epoxy (M85)	644	400	543	---	---	529

¹ GR stands for glass reinforced.

² Optical percent transmission data was off scale. Data was included in average.

TABLE 4. PERCENT WEIGHT LOSS FOR NONFLAMING EXPOSURE							
Pipe Material (Lab Mark)	Weight Loss by Sample Number (%)						Average Weight Loss % ¹
	S1	S2	S3	S4	S5	S6	
GR Epoxy (M80) ²	9.1	5.5	7.1	---	---	---	7
Polyvinyl Chloride (M81)	18.3 ³	28.3	28.1	---	34.6	27.7	30
GR Phenolic (M82)	7.3	6.1	4.4	---	---	---	6
GR Epoxy (M83)	8.4	6.6	7.5	---	---	---	7
GR Vinyl Ester (M84)	15.1 ³	5.6	7.7	5.5	7.0	---	6
GR Epoxy (M85)	6.4	6.3	8.0	---	---	---	7

¹ Average is of the actual values, not the rounded values presented.
² GR stands for glass reinforced.
³ Data was not included in the average.

TABLE 5. PERCENT WEIGHT LOSS FOR FLAMING EXPOSURE							
Pipe Material (Lab Mark)	Weight Loss by Sample Number (%)					Average Weight Loss % ¹	
	S4	S5	S6	S7	S8		
GR Epoxy (M80) ²	28.7	37.8	---	29.5	---	32	
Polyvinyl Chloride (M81)	59.4	---	---	46.2	57.9	55	
GR Phenolic (M82)	11.5	12.4	25.3	---	---	16	
GR Epoxy (M83)	28.9	24.4	26.9	---	---	27	
GR Vinyl Ester (M83)	---	---	27.6	31.9	35.4	32	
GR Epoxy (M85)	16.6	8.2	15.1	---	---	13	

¹ Average is of the actual values, not the rounded values presented.
² GR stands for glass reinforced.

A physical examination was made after each test for specimen damage. The least damage occurred with the fiberglass reinforced phenolic resin pipe. The greatest damage appeared on the polyvinyl chloride pipe which formed an intumescent layer that was up to 19 mm in depth. The fiberglass reinforced vinylester and epoxy resin pipes had intermediate damage.

3.3 Discussion

3.3.1 Nonflaming Tests

The pipe materials can be rank ordered in terms of the quantity of smoke produced. The average value of the specific optical density, D_m , is given in Table 6 in order of increasing smoke density for the nonflaming fire exposure. The fiberglass reinforced phenolic resin pipe was lowest with a value of 2. A fiberglass reinforced epoxy resin was highest with a value of 209. This latter sample was exceptional in that it was fabricated from an 11-inch flange section that was flatter than the other samples. The two other samples of epoxy resin pipes were 136 and 201. The polyvinyl chloride pipe was intermediate at a value of 179. Based on its value of 2 for D_m , the phenolic resin pipe would be expected to present less of a threat to life safety.

Although not required by the test method, it is useful to measure the weight loss of the test specimen. Values for the average specific weight loss for each material are summarized in Table 7 for the nonflaming tests. The low value of smoke density associated with the phenolic resin is reflected in its low specific weight loss of 0.4 kg/m^2 . Closely similar values were found for the vinylester resin and two of the epoxy resin pipes. The epoxy resin sample constructed from a flange and the polyvinyl chloride pipe were substantially higher at 0.9 and 1.5 kg/m^2 , respectively. Although outside the scope of this project, this information can be useful in developing a hazard analysis in which the estimated toxicity of the "smoke" is related to the rate of mass loss and the toxicity potential of the fire products.

3.3.2 Flaming Tests

A similar ranking process can be performed for the flaming exposure tests. Values for D_m and specific weight loss are given in Tables 6 and 7 respectively. For the flaming exposure conditions, most of the D_m values are about 500. An exception is the fiberglass reinforced phenolic resin pipe at 16. With this exception the D_m values indicate that these pipes would form a very dense smoke and would be hazardous. The weight loss values support this conclusion.

Table 6. RANK ORDER OF NONMETAL PIPES WITH RESPECT TO SPECIFIC OPTICAL DENSITY

Exposure	Material Type (Lab Mark)	Average Specific Optical Density (Dm)
NONFLAMING	GR Phenolic Resin (M82)	2
	GR Vinyl Ester (M84)	40
	GR Epoxy Resin (M80)	136
	Polyvinyl Chloride (M81)	179
	GR Epoxy Resin (M83)	201
	GR Epoxy Resin (M85) ¹	209
FLAMING	GR Phenolic Resin (M82)	16
	Polyvinyl Chloride (M81)	329
	GR Epoxy Resin (M80)	496
	GR Epoxy Resin (M85) ¹	529
	GR Epoxy Resin (M83)	> 535
	GR Vinyl Ester (M84)	565

¹ Specimens made from an 11-inch flange.

Table 7. RANK ORDER OF NONMETAL PIPES WITH RESPECT TO SPECIFIC WEIGHT LOSS ¹		
Exposure	Material Type (Lab Mark)	Average Specific Weight Loss (Kg/m ²)
NONFLAMING	GR Vinyl Ester (M84)	0.3
	GR Epoxy Resin (M80)	0.4
	GR Phenolic Resin (M82)	0.4
	GR Epoxy Resin (M83)	0.4
	GR Epoxy Resin (M85) ²	0.4
	Polyvinyl Chloride (M81)	1.5
FLAMING	GR Phenolic Resin (M82)	1.2
	GR Epoxy Resin (M83)	1.6
	GR Vinyl Ester (M84)	1.6
	GR Epoxy Resin (M80)	1.6
	GR Epoxy Resin (M85) ²	1.8
	Polyvinyl Chloride (M81)	2.9
¹ Weight loss per unit of sample surface area. ² Specimens made from an 11-inch flange.		

3.4 Phase 1 - Comments on the Test Method

The equipment and laboratory procedures for the ASTM E 662 have been developed for flat test specimens and the test protocol cautions against the testing of materials with curved surfaces. No quantitative information is available on the extent to which curvilinear surfaces change final results (i.e., Dm). Further, since the manufacturing processes for commercial pipes produce different resin to fiberglass ratios at the exposed surface than can be made using flat test samples, flat test samples would not be a representative of the commercial end product.

Therefore, the test protocol was modified to use production pipes having an exposed surface area equal to that prescribed for the normal flat test specimens. Because of the curvature, the heat flux is somewhat lower and a fixed distance between the pipe surfaces and the furnace cannot be maintained. This spacing difference affects the rate of circulation of combustion products into the furnace. Additional studies would be needed to define the incident flux for various curved surfaces and the effect of furnace to sample distances on D_m . An alternate approach, using several "slices" of pipe cemented together to cover the test surface area, was not used because of potential difficulties associated with interactive edge effects at the joints.

All tests were made using pipes mounted to simulate a horizontal installation. In addition to reducing the number of tests required, there were two major considerations for using this approach. First, most of the exposed pipes onboard a ship are installed in a horizontal pipe chase. This mounting therefore approximates the end use conditions better than a vertical installation. Secondly, during flaming exposure tests the standard burner has five flame ports, two of which impinge onto the test sample with the others being directed downward into the trough used to catch thermoplastic drippings. The two which impinge are outboard flame holders and would not impinge directly onto a 2-inch pipe mounted vertically using the equivalent surface area approach. The use of the nonstandard flame holder which has five straight flame ports is a possible alternative method.

4.0 PHASE 2

The objective of this phase was to investigate the effects of sample mounting orientation and pipe diameter on the quantity of smoke produced. The two pipe materials used in this phase were PVC and phenolic.

4.1 Technical Approach

4.1.1 Test Protocol

The test protocol for Phase 2 is the same as described in 3.1.1 with several exceptions. The first exception is that the test specimens were mounted to simulate installation in a vertical pipe chase in addition to the horizontal orientation of Phase 1. The second exception is that samples were prepared from pipes with nominal diameters of 3/4-inch, 2-inch, 4-inch, and 6-inch.

The third exception is that the samples were not conditioned prior to testing. Conditioning was considered unnecessary as these test specimens were unlikely to absorb moisture and the objective was to make a relative comparison.

The last exception is that the exposed surface area for the nominal 3/4-inch PVC pipe samples was not standard. That diameter of pipe is too small to form a test specimen from a single piece of pipe with a surface area equivalent to a flat test specimen. This deviation from the standard exposed sample area is acceptable for making a relative comparison of the effect of orientation.

4.1.2 Materials/Constructions

Two pipe materials used in this phase were PVC and phenolic; the sources of both were the same as in Phase 1.

Two different sample constructions were used for the 3/4-inch PVC samples. The pipe was split lengthwise in half. For one construction, one half of the pipe was mounted on the test specimen holder. The surface area of this configuration is slightly more than one half of the standard.

The second construction had two halves mounted side by side. The surface area of this construction is approximately one fourth greater than the standard but the degree of the exposure for part of the area is much less than for 2-inch pipes. Part of the surface area is almost perpendicular to the plane of the radiant panel and the portions where the two halves abut are partially shielded.

4.2 Test Results

The tests results are summarized in Table 8 for the nonflaming exposure and in Table 9 for the flaming exposure. The number of individual test runs are indicated in parenthesis along with the range of specific optical density. The data for the 2-inch diameter pipes in the horizontal orientation is from Phase 1. For all other tests, the laboratory data sheets are in Appendix C.

4.3 Discussion

4.3.1 Effect of Orientation

The concern on orientation of the sample dealt with the impingement of the flames on the sample during the flaming exposure. As discussed in 3.1.1 and 3.4, the flame ports that normally impinge on the sample are the outboard flame ports. The heat from these outboard flame ports would not necessarily impinge on 2-inch pipe samples mounted vertically using the equivalent surface area approach.

For the nonflaming exposure, mounting the sample vertically or horizontal appears to have minimal, if any, effect on specific optical density. The data in Table 8 for the 0.75-inch PVC pipe, the 6-inch PVC pipe, and the 2-inch phenolic

pipe clearly support this conclusion. The data for the 2-inch PVC pipe, the 4-inch PVC pipe, and the 4-inch phenolic pipe do not refute the conclusion as the differences are within the normal scatter.

Table 8. SPECIFIC OPTICAL DENSITY (D _m) FOR NONFLAMING EXPOSURE		
In parenthesis is the number of test runs (N) with the range of specific optical densities if more than one run.		
Test Specimen	ORIENTATION	
	Horizontal	Vertical
PVC pipe (M81)		
3/4-inch nominal single length	80 (N=3: 64 - 102)	78 (N=3: 69 - 95)
two lengths	158 (N=1)	162 (N=2: 154 - 171)
2-inch nominal single length	179* (N=4: 146 - 201)	132 (N=1)
4-inch nominal single length	146 (N=1)	133 (N=1)
6-inch nominal single length	75 (N=3: 69 - 78)	75 (N=3: 71 - 76)
Phenolic pipe (M82)		
2-inch nominal single length	2* (N=3: 1 - 2)	2 (N=1)
4-inch nominal single length	2 (N=1)	6 (N=1)
* - Data from Phase 1. Samples had been conditioned.		

Table 9. SPECIFIC OPTICAL DENSITY (Dm) FOR FLAMING EXPOSURE

In parenthesis is the number of test runs (N) with the range of specific optical densities if more than one run.

Test Specimen	ORIENTATION	
	Horizontal	Vertical
PVC pipe (M81) 2-inch nominal single length	329* (N=3: 300 - 353)	587 (N=1)
4-inch nominal single length	307 (N=1)	594 (N=1)
Phenolic pipe (M82) 2-inch nominal single length	16* (N=3: 15 - 18)	6 (N=2: 1- 11)
4-inch nominal single length	21 (N=1)	19 (N=2: 16- 22)

* - Data from Phase 1. Samples had been conditioned.

For the flaming exposure, the effect of the orientation appears to depend on the pipe material. The horizontal orientation resulted in lower specific optical densities for PVC than the vertical orientation. The results are mixed for the phenolic samples. One possible explanation for the vertical orientation resulting in higher specific optical density for PVC pipe is that more of the PVC fell into the trough; perhaps the molten PVC had a greater tendency to be trapped in the sample holder when mounted in the horizontal position.

4.3.2 Effect of Pipe Diameter

The concern on pipe diameter is whether testing a single pipe size is sufficient or will all sizes have to be tested. Pipe diameter appears to have a definite impact on smoke production based on the results presented in Table 10. That data

⁹ Confirmation of this is not possible as those observations were not recorded.

is for PVC pipe in the nonflaming exposure. The 6-inch diameter PVC pipe has a specific optical density (Dm) of about half of that of the smaller pipes. Thus, test results using 6-inch PVC pipes would not be indicative of the smoke production of smaller diameter pipes.

Table 10. EFFECT OF PIPE DIAMETER FOR PVC PIPE				
Sample Orientation and Pipe Diameter	Wall Thickness (mm)	Dm	Weight Loss (g)	Dm/g
Horizontal				
2-inch	3.9	179	7.26	25.1
4-inch	6.0	146	5.96	24.5
6-inch	7.1	75	6.12	12.3
Vertical				
2-inch	3.9	132	7.05	18.7
4-inch	6.0	132	7.47	17.8
6-inch	7.1	75	5.59	13.5
Data is for nonflaming exposure.				

The variation of smoke production with pipe diameter appears to be due to a change in the combustion process. As shown in Table 10, the weight loss for each diameter of pipe is similar. Therefore the difference can not be lower mass loss due to the greater thermal mass of the larger diameter pipes. For the 2-inch and 4-inch pipes, each gram of PVC consumed appears to produce roughly the same amount of smoke (Dm/g). For the 6-inch pipes, each gram of PVC consumed produces a third to half of the smoke of the smaller diameter pipes. This variation in smoke production reflects either the actual quantity of smoke or the obscuration power of the smoke. Whatever the case may be, the situation is not a simple one that can be gotten around by engineering judgment; testing will be required.

5.0 PHASE 3: CODE OF PRACTICE

The ASTM E 662 test procedure was designed for use with flat surfaces. The sample mounting procedure must be modified to adapt the test for use with curved surfaces (Figure 1). The modifications presented here apply to material surfaces characterized by simple moderate curvatures such as pipes. The modifications that were developed and the rationale used to formulate these modifications are summarized below:

1. Tests will be made for each pipe material and pipe size.

Rationale: The effects of wall thickness and variation in material compositions on the quantity of smoke developed are not well known. Discussions with pipe manufacturers have revealed that flat test specimens representative of fiberglass reinforced pipes would be difficult, if not impossible, to make. The principle reason cited was the difficulty in maintaining resin to glass ratios for the exposed surface areas that would be consistent with those in the pipe wall. Therefore, tests may be needed for each pipe diameter for a given product line. Additional data may show that the variation in wall thickness with diameter is insignificant relative to the pass/fail criteria. If so, less extensive testing may be possible.

2. When the nonmetal pipes are to include fireproofing or coatings, the composite structure consisting of the segmented pipe wall and fireproofing shall be tested.

Rationale: The tests should be performed on materials in their end-use configurations. In this case the end-use is with fireproofing. The fire properties of the fireproofed pipe assembly may differ from either those of the base pipe material or the fireproofing material.

3. The thickness of the fireproofing will be the minimum thickness specified for the intended usage.

Rationale: In most cases the fireproofing will consist of an insulative coating. Assuming that the smoke produced is generated mostly by the pipe material, the smoke values will increase with decreasing thickness of the fireproofing. Therefore the tests should be performed using the minimum thickness specified for the intended usage.

4. The test sample shall be equivalent in exposed surface area to a flat surface 76 mm by 76 mm.

Rationale: The equivalent area is defined as the exposed surface of a normal flat surface. For a 76 mm x 76 mm test

sample, this area is 57.76 cm². Because of the curvature of a pipe wall, a sample covering the normal exposed area of the sample holder would expose a larger surface area. Since the smoke produced is proportional to the total exposed area, higher smoke values would be expected. The equivalent area is therefore defined as an exposed curved surface of 57.76 cm².

5. The samples will be mounted on calcium silicate board.

Rationale: The test protocol requires the use of calcium silicate board.

6. The test samples will be fabricated by cutting pipe and applied fireproofing lengthwise into individual sections and then assembling the sections into a test sample as representative as possible of a flat surface.

Rationale: The test method was developed for use on flat surfaces. The pass/fail criteria are based on experience gained with flat surfaces. The pipes are sectioned lengthwise in order to reduce the effect of curved pipe surfaces on the production of smoke. The principal concern with the curved surface is the change in incident heat flux on the sample. The flux from the heating coil varies as a function of distance. The use of a quasi-flat surface avoids the need for the development of a correction factor or alternative pass/fail criteria. Either alternative would complicate the use of the test procedure for both regulators and manufacturers.

7. All cuts will be made perpendicular to the pipe wall.

Rationale: Cutting the pipe perpendicular to the pipe wall provides a uniform sample thickness. Other modes of cutting would result in a variable thickness and in some cases expose the interior of the pipe wall. The walls of fiberglass pipes are constructed of layers; the thermal and chemical properties may vary with the layers. Changing the respective ratios of the various layers could result in an unrepresentative quantity of smoke being produced.

8. The test samples will be mounted such that the sample uses the entire horizontal extent of the sample holder (See Figure 1).

Rationale: Other than for the sake of consistency, this requirement is necessary for the flaming exposure. The flame jets used in a flaming exposure extend from the left side to the right side of the sample holder. Testing with an equivalent surface area results in the sample not filling the entire area of the sample holder. The unfilled or bare area increases as the

pipe diameter decreases. If the pipe sample is mounted to use the entire vertical extent of the sample holder, the left and right sides of the face of the sample holder is bare. As a result, the flames and heat from the outboard flame jets may not impinge on the sample. Mounting the sample horizontally in the sample holder exposes the sample to the flames and heat from all of the flame jets. This provides a fire exposure more consistent with that of a flat test sample.

9. The highest part of the exposed surface will pass through the center of the test sample holder.

Rationale: This requirement ensures that the sample will be exposed to the highest heat flux. Any flaming is likely to impinge on the center of a horizontally mounted test specimen.

10. The individual pipe sections will be mounted so that the highest part of the exposed surface of the fireproofing is in the same plane as the surface of a normal test sample (See Figure 1).

Rationale: The flux from the heating coil varies as a function of distance. The part of the curved surface above the normal plane of the backing board is closer to the heating source and receives a higher heat flux. For a sample mounted below the normal plane the heat flux is less. By mounting the sample in the manner prescribed, intumescent materials can be evaluated. The material will start in the heat flux range of slightly below normal to normal and expand into a higher heat flux range.

11. The space between the concave unexposed surface of the test sample and the surface of the calcium silicate backing board will be void.

Rationale: The void space simulates a dry pipe configuration. In a dry pipe there is no liquid to transfer the heat away from the inner pipe wall. Therefore the decomposition responsible for the production of smoke can occur more rapidly. By leaving the space void, rather than back filling with an insulating wool packing, the convective heat flux in a dry pipe may be simulated.

12. The space between the top of the exposed test surface and the bottom edge of the sample holder frame, where the pipe extends under the frame, will be filled with a high temperature insulating wool.

Rationale: Unlike a flat surface, the lip of the test holder does not protect the edges of a curved sample from the incident radiant heat flux. This results in greater surface area for exposure and increases the quantity of smoke produced. The

use of a high temperature insulating wool to shield this additional surface area provides a fixed area of exposure. This provides a more consistent basis for comparing flat and curved materials.

13. The test samples will be held in place by the edges of the test frame and, if necessary, by wire (#18 gage nichrome recommended).

Rationale: In most cases, the lip of the test sample holder will hold the test sample in place. If the sample sags, wire may be necessary to hold the test sample in place. This is likely in the case of thermoplastic materials undergoing flaming exposure tests. Eighteen gage nichrome wire is adequate for this purpose when the calcium silicate backing is drilled and the wire is tied on the back side of the backing.

6.0 CONCLUSIONS

The ASTM E 662 test protocol can be modified to allow the determination of specific optical density for nonmetallic pipes. Using these modifications, it was found that:

- a. D_m ranged from 2 to 209 for nonflaming exposures.
- b. D_m ranged from 16 to 563 for flaming exposures.
- c. The phenolic pipe did not produce significant amounts of smoke under either flaming or nonflaming exposures. The low D_m values indicate that this material would not threaten life safety due to smoke obscuration.
- d. The polyvinyl chloride, vinylester, and epoxy pipes produced significant amounts of smoke under flaming exposures.
- e. The composite pipes can be rank ordered with respect to D_m . The rank order is not the same for flaming and nonflaming exposures. Although the relationship between rank and potential threat to life safety in a real fire is not fully established, the phenolic resin pipe would not be expected to increase significantly the threat to life safety.
- f. Orientation of sample, horizontally run versus vertically run pipe, can affect the results depending on the pipe material. Changing the orientation of the mounting of the sample did affect the results for PVC pipe in the flaming exposure. For the nonflaming exposure, the effect is minimal.

- g. Pipe diameter did make a difference in smoke production values for PVC pipes in the nonflaming exposure. As the mechanism for the difference in smoke production is not readily explainable, no conclusion is possible on whether it is possible to limit testing to certain diameters of pipes.

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3. Sub-Committee on Fire Protection 1990b. "Report to the Maritime Safety Committee," FP 35/20, International Maritime Organization.
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APPENDIX A
LIST OF MATERIALS

M80* GREENTHREAD** --A fiberglass reinforced epoxy resin pipe--
Yellow green in color with visible filaments.

Manufacturer
Specifications:

Laboratory
Measurements

Size: 2-inch
O.D.: 60.3 mm
I.D.: 54.5 mm
Wall Thickness: 3 mm
Weight: 0.9 kg/m
Thermal Conductivity: 0.40 W/(m · K)
Hazen Flow Factor: 150
Coefficient of Linear Thermal Expansion:
2.3 x 10E-5 (m/m)/K

Wall Thickness: 3 mm

Manufacturer: Smith Fiberglass Products Inc.
A.O. Smith
2700 W. 65th St.
Little Rock, Arkansas 72209-8592

M81* POLYVINYL CHLORIDE PIPE -- White -- Schedule 40, Type 1.

Manufacturer
Specifications

Laboratory
Measurements

Schedule 40, Type 1
Meets ASTM D-2665 and D-1785

Wall Thickness: 5 mm
I.D. = 51 mm

Manufacturer: Charlotte Plastics

M82* CHEMTITE** -- A fiberglass reinforced phenolic resin pipe --
Brown --

Manufacturer
Specifications

Laboratory
Measurements

Size: 2-inch
O.D.: 60.4 mm
I.D.: 51 mm
Wall Thickness: 4.6 mm
Weight: 1.48 kg/m
Thermal Conductivity: 0.3 -0.4 W/(m · K)
Hazen Flow Factor: 145
Thermal Expansion: 9 - 13 x 10E-6(m/m)/K

Wall Thickness: 5 mm

Manufacturer: Haveg Division
Ametek
900 Greenbank Road,
Wilmington, Delaware 19808

* Laboratory Mark designating the specific commercial pipe used
for testing

** Trade Name

M83* BONDSTRAND 2000M** -- A filament wound fiberglass reinforced epoxy pipe with a 0.02 inch (0.5 mm) integral resin-rich epoxy liner -- black

Manufacturer
Specifications

Laboratory
Measurements

Size: 2-inch
I.D.: 53 mm
Wall Thickness: 4 mm
Weight: 1.2 kg/m
Thermal Conductivity: 0.33 W/(m · K)
Thermal Expansion: 1.8×10^{-5} (m/m)/K
Hazen Flow Factor: 150

Wall Thickness: 4 mm

Manufacturer: Ameron
Fiberglass Pipe Division
P.O. Box 801148
Houston, Texas 77280

M84* POLYTHREAD** -- A fiberglass reinforced vinyl ester resin pipe with a glass mat reinforced vinyl ester liner -- Light green with green and red filaments visible.

Manufacturer
Specifications

Laboratory
Measurements

Size: 2-inch
O.D.: 60.3 mm
I.D.: 54.2 mm
Wall Thickness: 3 mm
Weight: 0.9 kg/m
Thermal Conductivity: 0.2 W/(m · K)
Hazen Flow Factor: 150
Coefficient of Linear Thermal Expansion:
 1.9×10^{-5} (m/m)/K

Wall Thickness: 3 mm

Manufacturer: Smith Fiberglass Products Inc.
A.O. Smith
2700 W 65th St.
Little Rock, Arkansas 72209-8592

* Laboratory Mark designating the specific commercial pipe used for testing

** Trade Name

M85* BONDSTRAND 7000M** -- A filament wound fiberglass reinforced epoxy resin pipe with conductive filaments in pipe wall -- Yellow-green with black filaments visible. Test samples taken from a flange section.

Manufacturer
Specifications

Laboratory
Measurements

Wall: (6 mm)

Thermal Conductivity: 0.33 W/(m · K)

Thermal Expansion: 18 x 10E-6 (m/m)/K

Manufacturer: Ameron
Fiberglass Pipe Division
P.O. Box 801148
Houston, Texas 77280

* Laboratory Mark designating the specific commercial pipe used for testing

** Trade Name

APPENDIX B
PHASE 1 TEST DATA

TEST DATA FOR PIPE M80

Laboratory Code: M80S1* Nonflaming Test

Date: 881010**

Operator: db

Initial Weight: 24.27 grams

Final Weight: 22.05 grams

Percent Weight Loss: 9.1 percent

Minimum transmission 12% at 20 minutes

Dm(corr.) = Dm - Dc = 122 - 4 = 118

Laboratory Code: M80S2 Nonflaming Test

Date: 881010

Operator: db

Initial Weight: 24.95 grams

Final Weight: 23.57 grams

Percent Weight Loss: 5.5 percent

Minimum transmission 12 % at 20 minutes

Dm(corr.) = Dm - Dc = 122 - 4 = 118

Laboratory Code: M80S3 Nonflaming Test

Date: 881010

Operator: db

Initial Weight: 23.86 grams

Final Weight: 22.16 grams

Percent Weight Loss: 7.1 percent

Minimum transmission 5.6 % at 15 minutes

Dm(corr.) = Dm - Dc = 165 - 4 = 161

Laboratory Code: M80S4 Flaming Test

Date: 881012

Operator: db

Initial Weight: 24.07 grams

Final Weight: 17.15 grams

Percent Weight Loss: 28.7 percent

Minimum transmission 0.009 % at 4.5 minutes

Dm(corr.) = Dm - Dc = 545 - 21 = 524

Laboratory Code: M80S5 Flaming Test

Date: 881013

Operator: db

Initial Weight: 25.40 grams

Final Weight: 15.8 grams

Percent Weight Loss: 37.8 percent

Minimum transmission 0.0085 % at 5 minutes

Dm(corr.) = Dm - Dc = 548 - 23 = 525

* Material 80, Sample 1

** Year, Month, Day of Test

Laboratory Code: M80S7 Flaming Test
Date: 881014
Operator: db
Initial Weight: 25.66 grams
Final Weight: 18.1 grams
Percent Weight Loss: 29.5 percent
Minimum transmission 0.10 % at 4 minutes
Dm(corr.) = Dm - Dc = 396 - 16 = 380

TEST DATA FOR PIPE M81

Laboratory Code: M81S1 Nonflaming Test
Date: 880930
Operator: db
Initial Weight: 25.29 grams
Final Weight: 20.67 grams
Percent Weight Loss: 18.3 percent
Transmission 23 % at 20 minutes
Dm(corr.) = Dm - Dc = 84 - 0 = 84

Laboratory Code: M81S2 Nonflaming Test
Date: 880930
Operator: db
Initial Weight: 25.27 grams
Final Weight: 18.12 grams
Percent Weight Loss: 28.5 percent
Minimum transmission 3.3 % at 20 minutes
Dm(corr.) = Dm - Dc = 187 - 0 = 187

Laboratory Code: M81S3 Nonflaming Test
Date: 880930
Operator: db
Initial Weight: 23.64 grams
Final Weight: 17.0 grams
Percent Weight Loss: 28.1 percent
Minimum transmission 3.0 % at 20 minutes
Dm(corr.) = Dm - Dc = 201 - 1 = 200

Laboratory Code: M81S4 Flaming Test
Date: 881004
Operator: db
Initial Weight: 25.82 grams
Final Weight: 10.48 grams
Percent Weight Loss: 59.4 percent
Minimum transmission 0.21 % at 20 minutes
Dm(corr.) = Dm - Dc = 353 - 16 = 337

Laboratory Code: M81S5 Nonflaming Test
Date: 881004
Operator: db
Initial Weight: 24.25 grams
Final Weight: 15.89 grams
Percent Weight Loss: 34.5 percent
Minimum transmission 7.8 % at 20 minutes
Dm(corr.) = Dm - Dc = 146 - 2 = 144

Laboratory Code: M81S6 Nonflaming Test
Date: 881004
Operator: db
Initial Weight: 24.90 grams
Final Weight: 18.0 grams
Percent Weight Loss: 27.7 percent
Minimum transmission 4.2 % at 20 minutes
Dm(corr.) = Dm - Dc = 182 - 2 = 180

Laboratory Code: M81S7 Flaming Test
Date: 881014
Operator: db
Initial Weight: 25.67 grams
Final Weight: 13.8 grams
Percent Weight Loss: 46.2 percent
Minimum transmission 0.53 % at 20 minutes
Dm(corr.) = Dm - Dc = 300 - 4 = 296

Laboratory Code: M81S8 Flaming Test
Date: 881014
Operator: db
Initial Weight: 25.97 grams
Final Weight: 10.93 grams
Percent Weight Loss: 57 percent
Minimum transmission 0.30 % at 20 minutes
Dm(corr.) = Dm - Dc = 333 - 4 = 329

TEST DATA FOR PIPE M82

Laboratory Code: M82S1 Nonflaming Test
Date: 880930
Operator: db
Initial Weight: 36.17 grams
Final Weight: 33.54 grams
Percent Weight Loss: 7.3 percent
Minimum transmission 96 % at 20 minutes
Dm(corr.) = Dm - Dc = 2 - 0 = 22 - 0 = 2

Laboratory Code: M82S2 Nonflaming Test
Date: 880930
Operator: db
 Initial Weight: 37.35 grams
 Final Weight: 35.09 grams
 Percent Weight Loss: 6.1 percent
 Minimum transmission 98 % at 20 minutes
 Dm(corr.) = Dm - Dc = 1 - 0 = 1

Laboratory Code: M82S3 Nonflaming Test
Date: 880930
Operator: db
 Initial Weight: 38.71 grams
 Final Weight: 37.01 grams
 Percent Weight Loss: 4.4 percent
 Minimum transmission 97 % at 20 minutes
 Dm(corr.) = Dm - Dc = 2 - 0 = 2

Laboratory Code: M82S4 Flaming Test
Date: 881005
Operator: db
 Initial Weight: 39.5 grams
 Final Weight: 34.96 grams
 Percent Weight Loss: 11.5 percent
 Minimum transmission 77 % at 20 minutes
 Dm(corr.) = Dm - Dc = 15 - 2 = 13

Laboratory Code: M82S5 Flaming Test
Date: 881005
Operator: db
 Initial Weight: 35.74 grams
 Final Weight: 31.30 grams
 Percent Weight Loss: 12.4 percent
 Minimum transmission 73 % at 20 minutes
 Dm(corr.) = Dm - Dc = 18 - 0 = 18

Laboratory Code: M82S6 Flaming Test
Date: 881005
Operator: db
 Initial Weight: 36.01 grams
 Final Weight: 26.89 grams
 Percent Weight Loss: 25.3 percent
 Minimum transmission 75 % at 25 minutes
 Dm(corr.) = Dm - Dc = 16 - 0 = 16

TEST DATA FOR PIPE M83

Laboratory Code: M83S1 Nonflaming Test

Date: 881003

Operator: db

Initial Weight: 29.78 grams

Final Weight: 27.28 grams

Percent Weight Loss: 8.4 percent

Minimum transmission 2.1 % at 20 minutes

Dm(corr.) = Dm - Dc = 221 - 2 = 219

Laboratory Code: M83S2 Nonflaming Test

Date: 881003

Operator: db

Initial Weight: 28.63 grams

Final Weight: 26.75 grams

Percent Weight Loss: 6.6 percent

Minimum transmission 3.2 % at 20 minutes

Dm(corr.) = Dm - Dc = 197 - 1 = 196

Laboratory Code: M83S3 Nonflaming Test

Date: 881003

Operator: db

Initial Weight: 29.50 grams

Final Weight: 27.29 grams

Percent Weight Loss: 7.5 percent

Minimum transmission 3.9 % at 20 minutes

Dm(corr.) = Dm - Dc = 186 - 3 = 183

Laboratory Code: M83S4 Flaming Test

Date: 881011

Operator: db

Initial Weight: 30.18 grams

Final Weight: 21.47 grams

Percent Weight Loss: 28.9 percent

Minimum transmission (offscale) at 4.5 minutes

Dm(corr.) = Dm - Dc = offscale = Dm > 528

Laboratory Code: M83S5 Flaming Test

Date: 881011

Operator: db

Initial Weight: 29.37 grams

Final Weight: 22.21 grams

Percent Weight Loss: 24.4 percent

Minimum transmission 0.035 % at 5.5 minutes

Dm(corr.) = Dm - Dc = 456 - 19 = 437

Laboratory Code: M83S6 Flaming Test
Date: 881011
Operator: db
 Initial Weight: 29.40 grams
 Final Weight: 21.5 grams
 Percent Weight Loss: 26.9 percent
 Minimum transmission 0.0024% at 5.5 minutes
 Dm(corr.) = Dm - Dc = 621 - 31 = 590

TEST DATA FOR M84

Laboratory Code: M84S1 Nonflaming Test
Date: 881003
Operator: db
 Initial Weight: 24.65 grams
 Final Weight: 20.94 grams
 Percent Weight Loss: 15.1 percent
 Minimum transmission 0.19 % at 20 minutes
 Dm(corr.) = Dm - Dc = 359 - 2 = 357

Laboratory Code: M84S2 Nonflaming Test
Date: 881003
Operator: db
 Initial Weight: 24.52 grams
 Final Weight: 23.14 grams
 Percent Weight Loss: 5.6 percent
 Minimum transmission 54 % at 20 minutes
 Dm(corr.) = Dm - Dc = 35 - 0 = 35

Laboratory Code: M84S3 Nonflaming Test
Date: 881003
Operator: db
 Initial Weight: 24.75 grams
 Final Weight: 22.84 grams
 Percent Weight Loss: 7.7 percent
 Minimum transmission 47 % at 20 minutes
 Dm(corr.) = Dm - Dc = 43 - 2 = 41

Laboratory Code: M84S4 Nonflaming Test
Date: 881004
Operator: db
 Initial Weight: 25.42 grams
 Final Weight: 24.02 grams
 Percent Weight Loss: 5.5 percent
 Minimum transmission 47 % at 20 minutes
 Dm(corr.) = Dm - Dc = 43 - 1 = 42

Laboratory Code: M84S5 Nonflaming Test
Date: 881004
Operator: db

Initial Weight: 25.28 grams
Final Weight: 23.51 grams
Percent Weight Loss: 7.0 percent
Minimum transmission 50 % at 20 minutes
Dm(corr.) = Dm - Dc = 40 - 1 = 39

Laboratory Code: M84S6 Flaming Test
Date: 881012
Operator: db

Initial Weight: 25.16 grams
Final Weight: 18.21 grams
Percent Weight Loss: 27.6 percent
Minimum transmission 0.01% at 5 minutes
Dm(corr.) = Dm - Dc = 528 - 21 = 507

Laboratory Code: M84S7 Flaming Test
Date: 881014
Operator: db

Initial Weight: 25.45 grams
Final Weight: 17.33 grams
Percent Weight Loss: 31.9 percent
Minimum transmission 0.0047 % at 6 minutes
Dm(corr.) = Dm - Dc = 582 - 29 = 553

Laboratory Code: M84S8 Flaming Test
Date: 881014
Operator: db

Initial Weight: 25.16 grams
Final Weight: 16.26 grams
Percent Weight Loss: 35.4 percent
Minimum transmission 0.0051 % at 5 minutes
Dm(corr.) = Dm - Dc = 578 - 26 = 552

TEST DATA FOR M85

Laboratory Code: M85S1 Nonflaming Test
Date: 880929
Operator: db

Initial Weight: 64.2 grams
Final Weight: 60.1 grams
Percent Weight Loss: 6.4 percent
Minimum transmission 4.9 % at 20 minutes
Dm(corr.) = Dm - Dc = 173 - 1 = 172

Laboratory Code: M85S2 Nonflaming Test
Date: Oct 1988
Operator: db

Initial Weight: 58.5 grams
Final Weight: 54.8 grams
Percent Weight Loss: 6.3 percent
Minimum transmission 3.1 % at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 199 - 2 = 197$

Laboratory Code: M85S3 Nonflaming Test
Date: 8810
Operator: db

Initial Weight: 64.7 grams
Final Weight: 59.5 grams
Percent Weight Loss: 8.0 percent
Minimum transmission 1.2 % at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 254 - 5 = 249$

Laboratory Code: M85S4 Flaming Test
Date: October 1988
Operator: db

Initial Weight: 65.25 grams
Final Weight: 54.41 grams
Percent Weight Loss: 16.6 percent
Minimum transmission 0.0016 % at 10 minutes
 $Dm(\text{corr.}) = Dm - Dc = 644 - 34 = 610$

Laboratory Code: M85S5 Flaming Test
Date: 881014
Operator: db

Initial Weight: 59.68 grams
Final Weight: 54.76 grams
Percent Weight Loss: 8.2 percent
Minimum transmission 0.093 % at 8 minutes
 $Dm(\text{corr.}) = Dm - Dc = 400 - 35 = 365$

Laboratory Code: M85S6 Flaming Test
Date: 881014
Operator: db

Initial Weight: 67.41 grams
Final Weight: 57.22 grams
Percent Weight Loss: 15.1 percent
Minimum transmission 0.0093 % at 10 minutes
 $Dm(\text{corr.}) = Dm - Dc = 543 - 50 = 493$

APPENDIX C
PHASE 2 TEST DATA

TEST DATA FOR 3/4-INCH PVC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.
- (2) Exposed area deviated from standard. Sample prepared by slicing the nominal 3/4-inch pipe lengthwise (i.e., along the diameter). Single length has an exposed surface area slightly half of the standard. Two lengths gives a surface area approximately a quarter over the standard.

Laboratory Code: M81-0.75-H1-T1* Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890823**
Operator: db

Initial Weight: 11.67 grams
Final Weight: 6.74 grams
Percent Weight Loss: 42.2 percent
Minimum transmission 17% at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 102 - 6 = 96$

Laboratory Code: M81-0.75-H1-T2 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890824
Operator: db

Initial Weight: 11.36 grams
Final Weight: 5.46 grams
Percent Weight Loss: 51.9 percent
Minimum transmission 33% at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 64 - 2 = 62$

Laboratory Code: M81-0.75-H1-T3 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890824
Operator: db

Initial Weight: 11.36 grams
Final Weight: not recorded
Percent Weight Loss: not recorded
Minimum transmission 28% at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 73 - 1 = 72$

Laboratory Code: M81-0.75-V1-T4 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890824
Operator: db

Initial Weight: 11.34 grams
Final Weight: 11.29 grams
Percent Weight Loss: 0.4%
Minimum transmission 30% at 20 minutes
 $Dm(\text{corr.}) = Dm - Dc = 69 - 1 = 68$

Laboratory Code: M81-0.75-V1-T5 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890825
Operator: db
 Initial Weight: 11.31 grams
 Final Weight: 4.91 grams
 Percent Weight Loss: 56.6%
 Minimum transmission 19% at 20 minutes
 Dm(corr.) = Dm - Dc = 95 - 1 = 94

Laboratory Code: M81-0.75-V1-T6 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890830
Operator: db
 Initial Weight: 11.30 grams
 Final Weight: 4.88 grams
 Percent Weight Loss: 56.8%
 Minimum transmission 30% at 20 minutes
 Dm(corr.) = Dm - Dc = 69 - 1 = 68

Laboratory Code: M81-0.75-V2-T7 Nonflaming Test
Sample Mounting: Two lengths running vertically
Date: 890830
Operator: db
 Initial Weight: 22.67 grams
 Final Weight: 14.66 grams
 Percent Weight Loss: 35.3%
 Minimum transmission 5.1% at 20 minutes
 Dm(corr.) = Dm - Dc = 171 - 2 = 169

Laboratory Code: M81-0.75-V2-T9 Nonflaming Test
Sample Mounting: Two lengths running vertically
Date: 891019
Operator: db
 Initial Weight: 24.26 grams
 Final Weight: 14.14 grams
 Percent Weight Loss: 41.7%
 Minimum transmission 6.8% at 20 minutes
 Dm(corr.) = Dm - Dc = 154 - 1 = 153

Laboratory Code: M81-0.75-H2-T10 Nonflaming Test
Sample Mounting: Two lengths running horizontally
Date: 891019
Operator: db
 Initial Weight: 24.21 grams
 Final Weight: 14.95 grams
 Percent Weight Loss: 38.2%
 Minimum transmission 6.3% at 20 minutes
 Dm(corr.) = Dm - Dc = 158 - 4 = 154

TEST DATA FOR 2-INCH PVC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.

Laboratory Code: M81-2-V1-T1 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890308
Operator: db
Initial Weight: 25.97 grams
Final Weight: 18.92 grams
Percent Weight Loss: 27.1%
Minimum transmission 10% at 20 minutes
Dm(corr.) = Dm - Dc = 132 - 1 = 131

Laboratory Code: M81-2-V1-T2 Flaming Test
Sample Mounting: One length running vertically
Date: 890314
Operator: db
Initial Weight: 26.23 grams
Final Weight: 8.24 grams
Percent Weight Loss: 69.3%
Minimum transmission 0.0043% at 20 minutes
Dm(corr.) = Dm - Dc = 587 - 2 = 585

TEST DATA FOR 4-INCH PVC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.

Laboratory Code: M81-4-V1-T1 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890310
Operator: db
Initial Weight: 20.92 grams
Final Weight: 13.45 grams
Percent Weight Loss: 35.7%
Minimum transmission 9.9% at 20 minutes
Dm(corr.) = Dm - Dc = 133 - 2 = 131

Laboratory Code: M81-4-V1-T1 Flaming Test
Sample Mounting: One length running vertically
Date: 890315
Operator: db
Initial Weight: 20.64 grams
Final Weight: 5.50 grams
Percent Weight Loss: 73.4%
Minimum transmission 0.0038% at 20 minutes
Dm(corr.) = Dm - Dc = 594 - 7 = 587

Laboratory Code: M81-4-H1-T1 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890317
Operator: db
Initial Weight: 20.18 grams
Final Weight: 14.22 grams
Percent Weight Loss: 29.5%
Minimum transmission 7.8% at 20 minutes
Dm(corr.) = Dm - Dc = 146 - 2 = 144

Laboratory Code: M81-4-H1-T2 Flaming Test
Sample Mounting: One length running horizontally
Date: 890317
Operator: db
Initial Weight: 20.10 grams
Final Weight: 6.78 grams
Percent Weight Loss: 66.3%
Minimum transmission 0.47% at 18 minutes
Dm(corr.) = Dm - Dc = 307 - 2 = 305

TEST DATA FOR 6-INCH PVC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.

Laboratory Code: M81-6-H1-T1 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890816
Operator: db
Initial Weight: 50.14 grams
Final Weight: 43.99 grams
Percent Weight Loss: 12.3%
Minimum transmission 25% at 20 minutes
Dm(corr.) = Dm - Dc = 79 - 1 = 78

Laboratory Code: M81-6-H1-T2 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890817
Operator: db
Initial Weight: 51.10 grams
Final Weight: 45.25 grams
Percent Weight Loss: 11.4%
Minimum transmission 26.5% at 20 minutes
Dm(corr.) = Dm - Dc = 76 - 1 = 75

Laboratory Code: M81-6-H1-T3 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890817
Operator: db
 Initial Weight: 50.50 grams
 Final Weight: 44.14 grams
 Percent Weight Loss: 12.6%
 Minimum transmission 29.5% at 20 minutes
 Dm(corr.) = Dm - Dc = 70 - 1 = 69

Laboratory Code: M81-6-V1-T4 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890817
Operator: db
 Initial Weight: 49.99 grams
 Final Weight: 44.02 grams
 Percent Weight Loss: 11.9%
 Minimum transmission 26.0% at 20 minutes
 Dm(corr.) = Dm - Dc = 77 - 1 = 76

Laboratory Code: M81-6-V1-T5 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890817
Operator: db
 Initial Weight: 50.23 grams
 Final Weight: 44.33 grams
 Percent Weight Loss: 11.8%
 Minimum transmission 27.0% at 20 minutes
 Dm(corr.) = Dm - Dc = 74 - 1 = 73

Laboratory Code: M81-6-V1-T6 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890817
Operator: db
 Initial Weight: 50.25 grams
 Final Weight: 45.36 grams
 Percent Weight Loss: 9.7%
 Minimum transmission 28.0% at 20 minutes
 Dm(corr.) = Dm - Dc = 72 - 1 = 71

TEST DATA FOR 2-INCH PHENOLIC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.

Laboratory Code: M82-2-V1-T1 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890308
Operator: db
Initial Weight: 35.17 grams
Final Weight: 33.97 grams
Percent Weight Loss: 3.4%
Minimum transmission 97% at 20 minutes
Dm(corr.) = Dm - Dc = 2 - 1 = 1

Laboratory Code: M82-2-V1-T2 Flaming Test
Sample Mounting: One length running vertically
Date: 890313
Operator: db
Initial Weight: 34.23 grams
Final Weight: 31.92 grams
Percent Weight Loss: 6.7%
Minimum transmission 99% at 20 minutes
Dm(corr.) = Dm - Dc = 1 - 0 = 1

Laboratory Code: M82-2-V1-T3 Flaming Test
Sample Mounting: One length running vertically
Date: 890321
Operator: db
Initial Weight: 34.27 grams
Final Weight: 30.15 grams
Percent Weight Loss: 12.0%
Minimum transmission 82% at 20 minutes
Dm(corr.) = Dm - Dc = 11 - 1 = 10

TEST DATA FOR 4-INCH PHENOLIC PIPE (UNCONDITIONED)

Deviations from procedure:

- (1) Samples were not conditioned prior to test.

Laboratory Code: M82-4-V1-T1 Nonflaming Test
Sample Mounting: One length running vertically
Date: 890310
Operator: db
Initial Weight: 43.50 grams
Final Weight: 41.31 grams
Percent Weight Loss: 5.0%
Minimum transmission 90% at 20 minutes
Dm(corr.) = Dm - Dc = 6 - 0 = 6

Laboratory Code: M82-4-V1-T2 Flaming Test
Sample Mounting: One length running vertically
Date: 890313
Operator: db
 Initial Weight: 39.30 grams
 Final Weight: 35.01 grams
 Percent Weight Loss: 10.9%
 Minimum transmission 68% at 20 minutes
 Dm(corr.) = Dm - Dc = 22 - 1 = 21

Laboratory Code: M82-4-V1-T3 Flaming Test
Sample Mounting: One length running vertically
Date: 890321
Operator: db
 Initial Weight: 39.62 grams
 Final Weight: 34.62 grams
 Percent Weight Loss: 12.6%
 Minimum transmission 75% at 20 minutes
 Dm(corr.) = Dm - Dc = 16 - 1 = 15

Laboratory Code: M82-4-H1-T1 Nonflaming Test
Sample Mounting: One length running horizontally
Date: 890317
Operator: db
 Initial Weight: 41.14 grams
 Final Weight: 39.86 grams
 Percent Weight Loss: 3.1%
 Minimum transmission 96% at 20 minutes
 Dm(corr.) = Dm - Dc = 2 - 1 = 2

Laboratory Code: M82-4-H1-T2 Flaming Test
Sample Mounting: One length running horizontally
Date: 890317
Operator: db
 Initial Weight: 41.21 grams
 Final Weight: 37.08 grams
 Percent Weight Loss: 10.0%
 Minimum transmission 69% at 20 minutes
 Dm(corr.) = Dm - Dc = 21 - 1 = 20