NFPA 267
Standard Method of Test for Fire Characteristics of Mattresses and Bedding Assemblies Exposed to Flaming Ignition Source

1998 Edition

NFPA®

National Fire Protection Association, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
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Fire Characteristics of Mattresses and Bedding Assemblies Exposed to Flaming Ignition Source

1998 Edition

This edition of NFPA 267, *Standard Method of Test for Fire Characteristics of Mattresses and Bedding Assemblies Exposed to Flaming Ignition Source*, was prepared by the Technical Committee on Fire Tests and acted on by the National Fire Protection Association, Inc., at its Fall Meeting held November 17–19, 1997, in Kansas City, MO. It was issued by the Standards Council on January 16, 1998, with an effective date of February 6, 1998, and supersedes all previous editions.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

This edition of NFPA 267 was approved as an American National Standard on March 31, 1998.

Origin and Development of NFPA 267

NFPA 267 was created as a new standard in 1994 to represent the current testing procedures for fire characteristics of mattresses and bedding assemblies exposed to a flaming ignition source. This procedure was developed to provide information that can be used to aid in the selection of mattresses and bedding assemblies that provide less of a contribution of heat, flame, smoke, and gases to fire scenarios. This standard was originally developed by research conducted by the National Institute of Standards and Technology (NIST), Underwriters Laboratories Inc. (UL), and the California Bureau of Home Furnishings and Thermal Insulation (BHFTI).

The 1998 edition contains minor editorial modifications and some technical revisions. The revisions include the appropriate gas flow and testing durations, which correlate with similar requirements found in related documents such as ASTM E 1590 and California Technical Bulletin 129.

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Committee Scope: This Committee shall have primary responsibility for documents on fire testing procedures for reviewing existing fire test standards and recommending appropriate action to NFPA; for recommending the application of and advising on the interpretation of acceptable test standards for fire problems of concern to NFPA technical committees and members; and for acting in a liaison capacity between NFPA and the committees of other organizations writing fire test standards. This Committee does not cover fire tests that are used to evaluate extinguishing agents, devices, or systems.

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Information on referenced publications can be found in Appendix C.

Chapter 1 General

1-1 Scope.

1-1.1 This test method, using an open calorimeter environment, shall be used to determine heat release, smoke density, weight loss, and generation of carbon monoxide of mattresses and bedding assemblies.

1-1.2* This test procedure shall be used to determine performance of mattresses and bedding assemblies without bedclothes exposed to a flaming ignition source. This performance data has been found to be useful in assessing the fire hazard of mattresses and bedding assemblies in occupancies that are identified as or considered to be public occupancies.

1-1.3* Heat release rate is indicated by measurement of oxygen depletion, and smoke generation is determined by smoke density measurement systems. Weight loss and carbon monoxide (CO) and carbon dioxide (CO_2) evolution are continuously recorded.

1-1.4* While this test method utilizes a full-scale open calorimeter, research has shown that both ASTM E 1590, *Standard Method for Fire Testing of Real Scale Mattresses,* and California Technical Bulletin 129, *Flammability Test Procedure for Mattresses for Use in Public Buildings,* provide comparable results for test specimens having heat release rates of 600 kW or less.

1-1.5 With respect to measurement of smoke and CO production, a quantitative relationship has not been established between measurements taken in the duct of the calorimeter exhaust system and measurements taken within the room. Accordingly, results of measurements of CO and smoke taken at different locations in different test environments shall not be considered equivalent.

1-2 Significance and Use.

1-2.1 This test method shall be used to determine the resulting fire performance characteristics of mattresses and bedding assemblies when exposed to a standard flaming ignition source.

1-2.2 The results from this procedure provide information that shall be permitted to be used as an aid in the selection of mattresses and bedding assemblies that provide for less contribution of heat, flame, smoke, and gases to fire scenarios.

1-2.3* Heat and smoke release rate measurements are sources of useful information for product development. They provide a quantitative measure of specific changes in fire performance caused by product modifications.

1-3 Summary of Test Method.

1-3.1 This procedure shall provide for exposure of full-size specimens to a standard flaming ignition source in an open calorimeter environment.

1-3.2 The standard ignition source shall be a gas burner.

1-3.3 Determinations shall be made and recorded for parameters that include density of smoke, concentrations of carbon monoxide and carbon dioxide, weight loss, heat release rate, and total heat release.

1-4 Definitions.

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

1-5 Units.

1-5.1 Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI).

1-5.2 If a value for measurement as given in this standard is followed by an equivalent value in other units, the first stated shall be regarded as the requirement. A given equivalent value shall be considered as approximate.

Chapter 2 Test Specimens

2-1 Test Specimens.

2-1.1 Size and Preparation. The test specimen shall consist of the actual mattress or bedding assembly item.

2-1.2 Conditioning. The test specimen shall be conditioned for at least 48 hours prior to test at 23°C ± 3°C (73°F ± 5°F) and a relative humidity of 50 percent ± 5 percent. Test specimens shall be tested within 10 minutes of removal from such conditions if the test conditions differ from those specified in 2-1.1.

Chapter 3 Test Equipment and Instrumentation

3-1 Ignition Source.

3-1.1 A 205-mm (8.07-in.) long "T" burner shall be constructed of 12 mm ± 1 mm (0.47 in. ± 0.039 in.) outside diameter stainless steel tubing with 0.89 mm ± 0.05 mm (0.034 in. ± 0.0019 in.) wall thickness *(see Figure 3-1.1)*. There shall be 14 holes at 45 degrees above the centerline and spaced 13 mm ± 1 mm (0.5 in. ± 0.039 in.) apart and 9 holes at 45 degrees below the centerline and spaced 13 mm ± 1 mm (0.5 in. ± 0.039 in.) apart. All holes shall be 1 mm ± 0.1 mm (0.039 in. ± 0.0039 in.) in diameter *(see Figure 3-1.1)*. The 1.07 m ± 0.2 m (42 in. ± 7.8 in.) straight arm of the burner shall be welded onto the rear of the burner at a 30-degree angle. The burner shall be mounted on an adjustable height pole and shall be balanced by a counterweight or other appropriate mechanism.

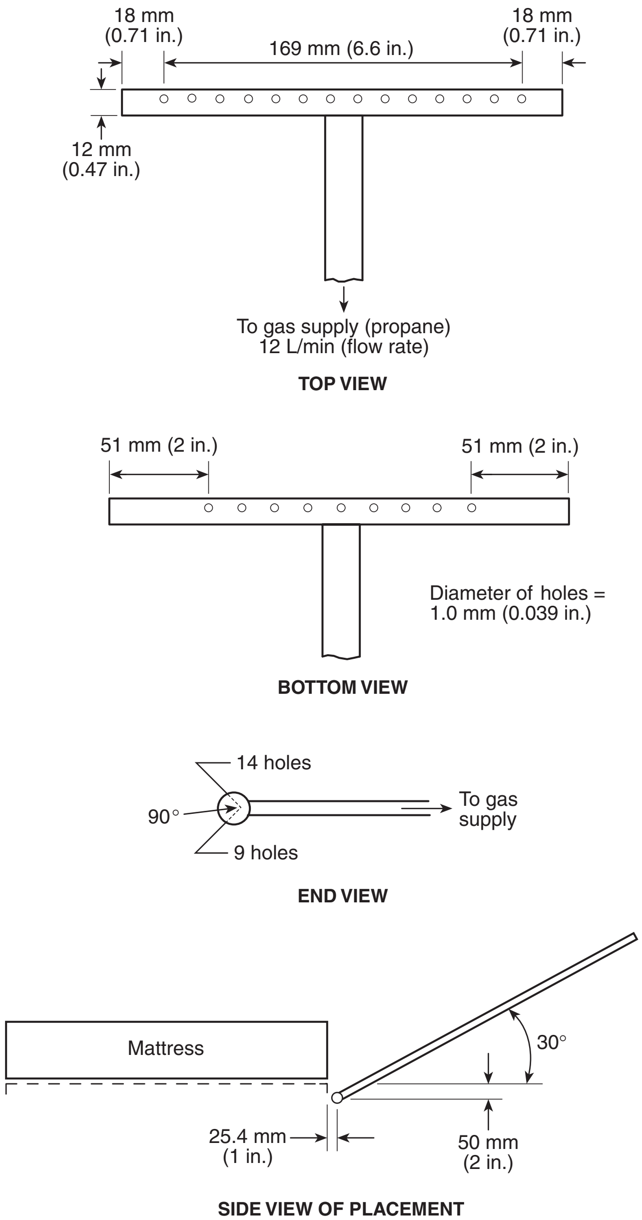

Figure 3-1.1 Propane gas burner.

3-1.2 The gas burner shall utilize commercial-grade propane gas as a fuel.

3-2 Collection — Exhaust System.

3-2.1 The hood shall be installed centrally above the weight-measuring system and test specimen. The face dimensions of the hood shall be 2.6 m ± 0.1 m × 2.6 m ± 0.1 m (8.53 ft ± 0.32 ft × 8.53 ft ± 0.32 ft) and the depth shall be 1.1 m ± 0.1 m (3.6 ft ± 0.32 ft). The hood shall exhaust into a plenum having a 0.9 m ± 0.05 m × 0.9 m ± 0.05 m (2.9 ft ± 0.16 ft × 2.9 ft ± 0.16 ft) cross section *(see Figure 3-2.1)*. Other hood sizes shall be permitted, provided they produce equivalent test results. The distance between the lower edge of the hood and the weight-measuring system shall be approximately 2.4 m (7.87 ft).

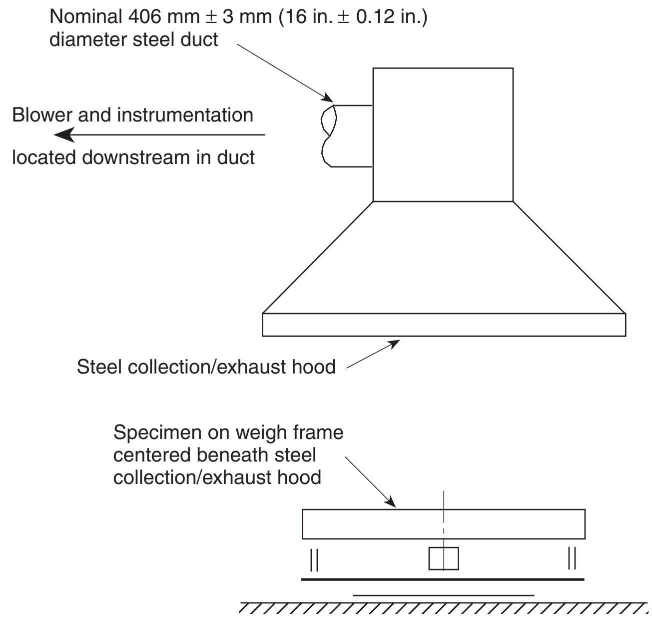

Figure 3-2.1 Collection hood and exhaust duct.

3-2.2* The exhaust duct connected to the plenum shall be 406 mm ± 3 mm (16 in. ± 0.12 in.) in diameter and shall have a circular aperture of 305 mm ± 3 mm (11.9 in. ± 0.12 in.) at its entrance.

3-2.3 The exhaust system shall have sufficient exhaust capacity to collect all products of combustion developed by the burning specimen. The exhaust hood system shall be capable of being operated within a range that varies from a minimum rate of 0.47 m^3/sec (16.6 ft^3/sec) to a maximum rate of at least 2.4 m^3/sec (84.8 ft^3/sec).

3-2.4 An alternate exhaust system design shall be permitted to be used if it has been shown to produce equivalent results.

3-3 Velocity Measuring Instruments.

3-3.1 The velocity in the exhaust duct shall be determined by measuring the differential pressure in the flow path with the use of a bidirectional probe, as shown in Figure 3-3.1, connected to an electronic pressure gauge or an equivalent measuring system. The probe shall consist of a stainless steel cylinder with a solid diaphragm in the center that divides it into two chambers. The probe shall measure 44 mm (1.7 in.) long and have an inside diameter of 22 mm (0.86 in.). The pressure taps on either side of the diaphragm shall support the probe.

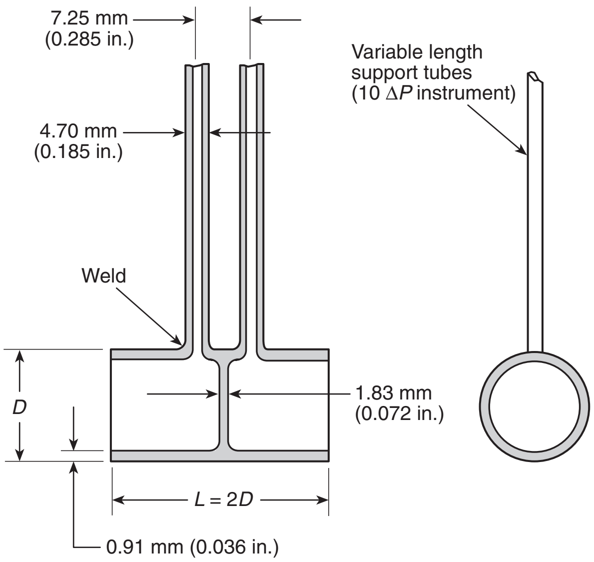

Figure 3-3.1 Bidirectional probe.

3-3.2 The axis of the probe shall be located at the centerline of the duct a minimum of 10 diameters downstream from the last turn in the duct. The taps shall be connected to a pressure transducer with a minimum resolution of 0.25 Pa (0.001 in. of water).

3-3.3 The temperature of the exhaust gas shall be measured upstream approximately 152 mm ± 15 mm (5.9 in. ± 0.6 in.) from the probe at the centerline of the duct with a No. 28 AWG (0.08 mm^2), Type K thermocouple with an inconel sheath having a 16-mm (0.62-in.) outside diameter and a thickness of 3 mm (0.12 in.).

3-4 Gas Sampling and Analysis Equipment.

3-4.1* A stainless steel gas sampling tube shall be located at least 10 diameters downstream from the last turn in the duct to obtain a continuously flowing sample for determining the oxygen concentration of the exhaust gas as a function of time. A suitable filter and cold trap shall be placed in line ahead of the analyzer to remove particulates and water. The oxygen analyzer shall be of the paramagnetic type and shall be capable of measuring the oxygen concentration in the range of from 0 percent to 21 percent with an accuracy of ±0.2 percent of full-scale setting. The signal from the oxygen analyzer shall attain 90 percent of the calibration value within 30 seconds after introducing a step change in composition of the gas stream flowing past the inlet to the sampling tube.

3-4.2* The gas sampling tube shall be located and defined as in 3-4.1. The carbon monoxide analyzer shall be capable of measuring the carbon monoxide in a range of from 0 percent to 1.0 percent with an accuracy of ±0.02 percent of full-scale setting. The signal from the analyzer shall attain 90 percent of the calibration value within 30 seconds after introducing a step change in composition of the gas stream flowing past the inlet to the sampling tube.

3-4.3* The gas sampling tube shall be as located and described in 3-4.1. The carbon dioxide analyzer shall be capable of measuring the carbon dioxide concentration in a range of from 0 percent to 10 percent with an accuracy of ±0.2 percent of full-scale setting. The signal from the analyzer shall attain 90 percent of the calibration value within 30 seconds after introducing a step change in composition of the gas stream flowing past the inlet to the sampling tube.

3-5 Smoke Density Measuring Instruments.

3-5.1 The smoke density measuring system shall be a white light system.

3-5.2 The lamp shall be of the incandescent filament type and shall operate at a color temperature of 2900 K ± 100 K. The lamp shall be supplied with stabilized direct current, stable within ±0.2 percent, including temperature and short-term and long-term stability.

3-5.3 The lens system shall be selected such that the lens shall have a diameter, *d*, chosen with regard to the focal length, *f*, so that $d/f \leq 0.04$.

3-5.4 The aperture shall be placed in the focus of the lens.

3-5.5 The detector shall have a spectrally distributed response according to the CIE photopic curve. The detector shall be linear within 5 percent for an output range of at least 3.5 decades. This linearity shall be checked periodically with calibrated optical filters that shall cover the entire range of the instrument.

3-5.6 The system shall be mounted on a horizontal section of duct at a point where it will be preceded by a straight run of duct [at least 12 diameters or 5.2 m (17 ft)] and with the light beam directed upward along the vertical axis of the duct. A photoelectric cell, whose output is directly proportional to the amount of light received, shall be mounted over the light source and connected to a recording device. The recording device shall have an accuracy within ±1 percent of full scale for indicating changes in the attenuation of incident light resulting from the passage of smoke, particulate, and other effluents. The distance between the light source lens and the photocell lens shall be 914 mm ± 102 mm (35.6 in. ± 3.9 in.). The cylindrical light beam shall pass through 76 mm ± 3 mm (2.9 in. ± 0.12 in.) diameter openings at the top and bottom of the duct, with the resultant light beam centered on the photocell.

3-5.7 An alternate smoke density measuring system shall be permitted to be used if it has been shown to produce equivalent results.

3-6 Weighing Platform.

3-6.1 Mass loss rate of the burning specimen shall be measured during the test by means of a weight-measuring device.

3-6.2 A weighing platform shall be used to support the test specimen during the test. A reinforced inorganic board having the dimensions 1.2 m ± 0.1 m × 2.4 m ± 0.1 m (3.9 ft ± 0.32 ft × 7.87 ft ± 0.32 ft) shall be located on top of the weighing platform. The weighing platform perimeter shall have a rim extending 0.1 m ± 10 mm (0.32 ft ± 0.39 ft) above the top surface of the inorganic board to prevent spillage of test material.

3-6.3 The weight-measuring device shall be capable of measuring the specimen mass up to at least 90 kg (198.5 lb) with an accuracy of at least ±150 g (0.33 lb). It shall be installed in such a way that the heat from the burning specimen and any eccentricity of the load do not affect the accuracy. Care shall be taken to avoid range shifts during measurements. All parts of the weight-measuring device shall be located below the top level of the slab.

3-6.4 The weighing platform shall support the base of the furniture specimen 127 mm ± 76 mm (5 in. ± 3 in.) above the floor.

3-6.5 The weighing platform shall be located beneath the collection hood at its geometric center.

3-7 Data Acquisition. A digital data acquisition system shall be used to collect and record oxygen, carbon monoxide, and carbon dioxide analyzer measurements; pressure gauge measurements; temperatures; smoke measurements; and weight-measuring device measurements. The speed and capacity of the data system shall be sufficient to collect the data every 5 seconds.

3-8 Photographic and Video Equipment. A camera and video equipment shall be used to record the test specimen performance throughout each test.

Chapter 4 Calibration

4-1 Calibration of Equipment.

4-1.1 The equipment and instrumentation shall be calibrated.

4-1.2 The heat release instrumentation shall be calibrated by burning propane. A gas burner shall be constructed with a 100 mm ± 6 mm (3.9 in. ± 0.23 in.) layer of Ottawa sand to provide the horizontal surface through which the gas is supplied. The gas supply to the burner shall be of commercial-grade propane and shall have a net heat of combustion of 46.4 MJ/kg ± 0.5 MJ/kg (20,000 Btu/lb ± 200 Btu/lb). The flow rate of propane shall be metered and kept constant throughout the calibration test. A heat release value of 160 kW shall be used for calibration. The test shall be conducted for a period of 10 minutes.

4-1.3 A calibration constant, *C,* shall be obtained as described in Chapter 6. A value for *C* differing more than 10 percent from the theoretical value shall not be permitted and the equipment shall be checked. For the exhaust duct configuration described in Section 3-2 and the velocity probe described in Section 3-3, *C* shall have a theoretical value of 2.8.

4-2 Daily Calibration.

4-2.1 Prior to the start of each day of testing, the equipment calibrations described in 4-2.2 through 4-2.7 shall be performed.

4-2.2 The oxygen analyzer shall be zeroed and spanned. The analyzer shall be zeroed by introducing 100 percent nitrogen gas to the instrument at the same pressure and flow rate as set for the test specimen combustion gases. The analyzer shall be spanned by introducing ambient duct air via the sample probe and adjusting the span to 20.95 percent oxygen. The spanning and zeroing process shall continue until adjustment-free accuracy is obtained.

4-2.3 Following zeroing and spanning, linearity of the oxygen analyzer response curve shall be verified by introducing bottled gas of a known oxygen concentration to the analyzer. The delay time of the analyzer shall be checked by introducing ambient duct air to the analyzer and noting the time at which the analyzer readings reach 90 percent of the final reading.

4-2.4 The CO analyzer and CO_2 analyzer shall be zeroed and spanned in the same manner as the oxygen analyzer. The analyzer shall be zeroed by introducing 100 percent nitrogen gas to the instrument at the same pressure and flow rate as set for the test specimen combustion gases. The analyzer shall be spanned by feeding each analyzer with bottled gas containing the selected concentration of span gas and adjusting for the response range of each analyzer.

4-2.5 The delay time of each analyzer shall be determined. The delay time shall be measured by introducing either a calibration span gas (for CO and CO_2) or a zero gas (for O_2) at the sample line just outside the duct and noting the time at which the analyzer readings reach 90 percent of the final reading.

4-2.6 The weight-measuring device shall be calibrated with known weights suitable for the capacity of the equipment and the specimen being tested.

4-2.7 Linearity of the smoke density measuring system shall be verified by interrupting the light beam with multiple calibrated neutral density filters to cover the range of the recording instrument. Transmittance values measured by the photometer, using neutral density filters, shall be within ±3 percent of the calibrated value for each filter.

Chapter 5 Test Procedure

5-1 Testing Procedure.

5-1.1 The test specimen and weighing platform shall be located as shown in Figure 3-2.1.

5-1.2 The initial exhaust hood flow rate shall be set at a minimum of 0.47 m^3/sec (16.6 ft^3/sec).

5-1.3 The burner shall be positioned 25 mm ± 3 mm (0.97 in. ± 0.12 in.) from the side and 51 mm ± 3 mm (2 in. ± 0.12 in.) below the item with the center of the burner at the centerline of the test specimen.

5-1.4 Data acquisition shall begin in order to monitor test instrumentation.

5-1.5 The gas flow rate to the burner shall be set at a volume flow rate of 12 L/min ± 0.5 L/min (3.2 gal/min ± 0.13 gal/min). Care shall be taken to allow free flow of propane through the burner holes. Periodic cleaning of soot deposits and blowing pressurized air through the tube shall be required.

5-1.6 The burner shall be ignited.

5-1.7 The exhaust hood flow rate shall be increased as required to collect all products of combustion from the test specimen.

5-1.8 The burner shall be removed from the test specimen after an exposure of 180 seconds ± 2 seconds.

5-1.9 The burner shall be turned off.

5-1.10 Combustion shall be allowed to continue until one or more of the following conditions are reached:

(a) All flaming combustion has ceased.

(b) Thirty minutes have elapsed from the time the burner was ignited.

Chapter 6 Calculations

6-1 Method of Calculation. The symbols used in this chapter shall be defined as in Section 6-2 and Appendix B. The equations in this chapter shall assume that only oxygen is measured.

Appropriate equations that shall be used for those cases where additional gas analysis equipment (CO_2, CO, water vapor) is used are provided in Appendix B. If a CO_2 analyzer is used and CO_2 is not removed from the oxygen sampling lines, then the appropriate equations in Appendix B shall be used.

6-2 Symbols. The following symbols are used in this chapter:

C = calibration constant using propane ($m^{1/2}kg^{1/2}K^{1/2}$

$\Delta H_c/r_o$ = net heat released per kg of O_2 consumed (kJ/kg), where ΔH_c equals netheat of combustion (kJ/kg) and r_o equals stoichiometric oxygen/fuel mass ratio

I = light intensity

I_o = light intensity with no smoke

k = extinction coefficient (m^{-1})

L = path length (m)

ΔP = orifice meter pressure differential (Pa)

$\dot{q}''$ = heat release rate per unit area (kW/m^2)

t = time (sec)

t_d = oxygen analyzer delay time (sec)

T_e = absolute temperature of gas at the orifice meter (K)

X_{O_2} = oxygen analyzer reading, mole fraction O_2

$X^0_{O_2}$ = initial value of oxygen analyzer reading

$X^1_{O_2}$ = oxygen analyzer reading, before delay time correction

6-3 Calibration Constant Using Propane. The calibration constant shall be obtained from the following equation:

$$C = \left[\frac{160}{1.10(12.77\times 10^3)}\right]\left(\sqrt{\frac{T_e}{\Delta P}}\right)\left(\frac{1.084-1.4X_{O_2}}{X^0_{O_2}-X_{O_2}}\right)$$

In this equation 160 corresponds to 160 kW propane supplied, 12.77×10^3 equals $\Delta H_c/r_o$ for propane, and 1.10 is the ratio of oxygen to air molecular weight.

6-4 Heat Release for Test Specimens.

6-4.1 Prior to performing additional calculations, the oxygen analyzer time shift shall be determined by the following equation:

$$X_{O_2}(t) = X^1_{O_2}(t-t_d)$$

6-4.2 The heat release rate then shall be determined by the following equation:

$$\dot{q}(t) = \left(\frac{\Delta H_c}{r_o}\right)1.10C\left(\sqrt{\frac{\Delta P}{T_e}}\right)\left[\frac{X^0_{O_2}-X_{O_2}(t)}{1.084-1.4X_{O_2}(t)}\right]$$

6-4.3 The value of ($\Delta H_c/r_o$) for the test specimen shall be set equal to 13.1×10^3 kJ/kg unless a more accurate value is known for the test specimen.

6-4.4 The total heat released during the first 10 minutes of the test shall be determined by the following equation:

$$\dot{q}''i = \sum_{i=0}^{10}\dot{q}''i(t)\Delta t$$

6-5 Smoke Obscuration.

6-5.1 The extinction coefficient (k) of smoke shall be determined by the following equation:

$$k = \frac{1}{L}\ln\left(\frac{I_0}{I}\right)$$

6-5.2 The smoke release rate *(SRR)* shall be calculated using the optical density per linear path length and the volumetric flow rate in the duct. The *SRR* shall be determined by the following equation:

$$SRR = km$$

In this equation *SRR* equals the smoke release rate in m^2/sec, k equals the extinction coefficient, and m equals the volumetric flow rate in m^3/sec referred to 298 K.

Chapter 7 Report of Results

7-1 Documentation. The following shall be reported for each test specimen:

(a) Test specimen identification or number
(b) Manufacturer or submitter
(c) Date of test
(d) Operator
(e) Composition or generic identification
(f) Details of preparation
(g) Number of replicate specimens tested
(h) Time to termination of test (sec)
(i) Maximum mass loss (kg)
(j) Peak rate of heat release (kW)
(k) Time to peak rate of heat release (sec)
(l) Maximum smoke release rate (m^2/sec)
(m) Maximum carbon monoxide concentration (ppm)
(n) Maximum carbon dioxide concentration (ppm)
(o) Pretest photographic record of test specimen.

Appendix A Explanatory Material

Appendix A is not a part of the requirements of this NFPA document but is included for informational purposes only. This appendix contains explanatory material, numbered to correspond with the applicable text paragraphs.

A-1-1.2 This procedure is based on California Technical Bulletin 129, *Flammability Test Procedure for Mattresses for Use in Public Buildings.* This test may not predict changes in fire performance due to aging, wear, leaching, or contamination during normal use or due to abuse.

A-1-1.3 This test method does not take into consideration any effect of potential vandalism. Vandalism of the composite mattress could change the fire performance characteristics of certain mattress construction.

A-1-1.4 For further information on other test environments, see the following publications:

"Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 1: Measuring the Hazards of Furniture Fires," by J. Quintiere.

"Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 2: Characterization of Ignition Source and Comparable Gas Burner," by T. Ohlemiller and K. Villa.

"Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 3: Full-Scale Chair Burns," by W. J. Parker, et al.

A-1-2.3 This procedure is not intended to be used for the evaluation of residential mattresses.

A-3-2.2 The locations for velocity, temperature, gas analysis, and smoke photometer shall be chosen to ensure that the products of combustion are well-mixed and not stratified at the sampling location. The general rule is for the duct to run a sufficient length (10 diameters) downstream from the last turn in the duct prior to location of instrumentation to provide for a fully developed gas flow. Mixing vanes shall be required in the duct if concentration gradients are found to exist.

A-3-4.1 The following information is provided for informational purposes only and has not been independently verified, certified, or endorsed by the NFPA or any of its Technical Committees.

One type of oxygen analyzer is a Beckman Instrument Model 755 paramagnetic-type oxygen analyzer. Other equivalent oxygen analyzers may be permitted to be used.

A-3-4.2 The following information is provided for informational purposes only and has not been independently verified, certified, or endorsed by the NFPA or any of its Technical Committees.

One type of carbon monoxide analyzer is a Horiba Instrument Model PIR-2000 analyzer. Other equivalent carbon monoxide analyzers may be permitted to be used.

A-3-4.3 The following information is provided for informational purposes only and has not been independently verified, certified, or endorsed by the NFPA or any of its Technical Committees.

One type of carbon dioxide analyzer is a Horiba Instrument Model PIR-2000 analyzer. Other equivalent carbon dioxide analyzers may be permitted to be used.

Appendix B Heat Release Calculations Using Additional Gas Analysis

This appendix is not a part of the requirements of this NFPA document but is included for informational purposes only.

B-1 Calculation of Heat Release with Additional Gas Analysis.

B-1.1 The equations used to calculate heat release rate in Chapter 6 assume CO_2 is removed from the gas sample in a chemical scrubber before oxygen is measured. Some laboratories are equipped to measure CO_2; in such a case, it is not necessary to remove the CO_2 from the oxygen line. The advantage is that the chemical scrubbing agent, which is costly and needs careful handling, can be avoided.

B-1.2 In this appendix, equations are provided that should be used when CO_2 is measured but *not* scrubbed out of the sampling lines. Two cases are considered. In the first case, part of the dried and filtered sample stream is diverted into infrared CO_2 and CO analyzers. In the second case, a water-vapor analyzer is also added. To avoid condensation, when measuring water-vapor concentration in the flow of combustion products, a separate sampling system with heated filters, heated sampling lines, and a heated analyzer is needed.

B-2 Symbols. The following symbols are used in this appendix:

$\Delta H_c / r_o$ = net heat released per kg of O_2 consumed kJ/kg, where equals net heat of combustion kJ/kg and equals stoichiometric oxygen/fuel mass ratio

M_a = molecular weight of air (kg/kmol)

M_e = molecular weight of the combustion products (kg/kmol)

$\dot{m}_e$ = exhaust duct mass flow rate (kg/sec)

t_d^1 = delay time of the CO_2 analyzer(s)

t_d^2 = delay time of the CO analyzer(s)

t_d^3 = delay time of the water-vapor analyzer(s)

$X_{CO_2}^0$ = initial CO_2 reading, mole fraction

X_{CO}^0 = initial CO reading, mole fraction

$X_{H_2O}^0$ = initial water-vapor reading, mole fraction

$X_{O_2}^a$ = ambient oxygen mole fraction (mol/mol)

$X_{CO_2}^1$ = CO_2 reading before delay time correction, mole fraction

X_{CO}^1 = CO reading before delay time correction, mole fraction

$X_{H_2O}^1$ = water-vapor reading before delay time correction, mole fraction

X_{CO_2} = CO_2 reading after delay time correction, mole fraction

X_{CO} = CO reading after delay time correction, mole fraction

X_{H_2O} = water reading after delay time correction, mole fraction

ϕ = oxygen depletion factor

B-3 Where CO_2 and CO Are Measured.

B-3.1 As in the case of the oxygen analyzer, measurements of CO_2 and CO should be time-shifted to take transport time in the sampling lines into account as follows:

$$X_{O_2}(t) = X_{O_2}^1(t + t_d)$$

$$X_{CO_2}(t) = X_{CO_2}^1(t + t_d^1)$$

$$X_{CO}(t)'''' = X_{CO}^1(t + t_d^2)$$

The delay times, t_d^1 and t_d^2, for the CO_2 and CO analyzers, respectively, are usually different (smaller) than the delay time, t_d, for the oxygen (O_2) analyzer.

B-3.2 The exhaust duct flow is determined as follows:

$$\dot{m}_e = C\sqrt{\frac{\Delta P}{T_e}}$$

B-3.3 The rate of heat release now can be determined as follows:

$$\dot{q} = 1.10\left(\frac{\Delta H_c}{r_o}\right)X_{O_2}^a\left[\frac{\phi - 0.172(1-\phi)\dfrac{X_{CO}}{X_{O_2}}}{(1-\phi)+1.084\phi}\right]\dot{m}_e$$

B-3.4 The oxygen depletion factor, ϕ, is calculated as follows:

$$\phi = \frac{X_{O_2}^0(1 - X_{CO_2} - X_{CO}) - X_{O_2}(1 - X_{CO_2}^0)}{X_{O_2}^0(1 - X_{CO_2} - X_{CO} - X_{O_2})}$$

B-3.5 The ambient mole fraction of oxygen (O_2) is determined as follows:

$$X_{O_2}^a = (1 - X_{H_2O}^0)(X_{O_2}^0)$$

B-3.6 The second value in the numerator of the factor in brackets in the equation in B-3.3 is a correction factor for incomplete combustion of some carbon to CO instead of CO_2. In fact, X_{CO} is usually very small, so that it can be disregarded in the equations in B-3.3 and B-3.4. The practical implication of this value is that a CO analyzer will generally not result in a noticeable increase in accuracy of heat release rate measurements. Consequently, the equations in B-3.3 and B-3.4 may be permitted to be used even if no CO analyzer is present by using the setting, $X_{CO} = 0$.

B-4 Where Water Vapor Is also Measured.

B-4.1 In an open combustion system, such as that used in this test method, the flow rate of air entering the system cannot be measured directly but is inferred from the flow rate measured in the exhaust duct. An assumption regarding the expansion due to combustion of the fraction of the air that is fully depleted of its oxygen is necessary. This expansion depends on the composition of the fuel and the actual stoichiometry of the combustion. A suitable average value for the volumetric expansion factor is 1.084, which is the factor for propane.

B-4.2 This expansion factor value is already incorporated within the equation in 6-4.2 and the equation in B-3.3 for $\dot{q}$. It can be assumed that the exhaust gases consist primarily of nitrogen, oxygen, CO_2, water vapor, and CO; thus, measurements of these gases can be used to determine the actual expansion. (It is assumed that the measurements of oxygen, CO_2, and CO refer to a dry gas stream, while the water-vapor measurement corresponds to total stream flow.) The mass flow rate in the exhaust duct is then more accurately determined by the following equation:

$$\dot{m}_e = C\sqrt{\frac{\Delta P}{T_e}}\sqrt{\frac{M_e}{M_a}}$$

B-4.2.1 The molecular weight, M_e, of the exhaust gases is determined as follows:

$$M_e = [4.5 + (1 - X_{H_2O})(2.5 + X_{O_2} + 4X_{CO_2})]4$$

B-4.2.2 Using 28.97 as the value for M_a, the heat release rate is determined as follows:

$$\dot{q}(t) = 1.10\left(\frac{\Delta H_c}{r_o}\right)(1 - X_{H_2O})\left[\frac{X_{O_2}^0(1 - X_{O_2} - X_{CO_2})}{1 - X_{O_2}^0 - X_{CO_2}^0} - X_{O_2}\right]\dot{m}_e$$

B-4.2.3 The following equation could be used to determine heat release rate when measuring O_2, CO_2, CO, and H_2O:

$$\dot{q}(t) = 1.10\left(\frac{\Delta H_c}{r_o}\right)(1 - X_{H_2O})\left[\phi - 0.172(1-\phi)\left(\frac{X_{CO}}{X_{O_2}}\right)\right]$$
$$\times\left[\frac{1 - X_{O_2} + -X_{CO_2} - X_{CO}}{1 - X_{O_2}^0 - X_{CO_2}^0}\right]\dot{m}_e X_{O_2}^0$$

B-4.3 The water-vapor readings used in the equation in B-4.2.2 are time-shifted in a similar way to those in the equations in B-3.1 for the other types of analyzers as follows:

$$X_{H_2O}^0(t) = X_{H_2O}^1(t - t_d^3)$$

Appendix C Referenced Publications

C-1 The following documents or portions thereof are referenced within this standard for informational purposes only and are thus not considered part of the requirements of this standard. The edition indicated here for each reference is the current edition as of the date of the NFPA issuance of this standard.

C-1.1 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 1590, *Standard Method for Fire Testing of Real Scale Mattresses,* 1996.

C-1.2 NIST Publications. U.S. National Institute of Standards Technology, U.S. Department of Commerce, Technology Administration National Technical Information Service, Springfield, VA 22161.

NIST 4360, "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 1: Measuring the Hazards of Furniture Fires," J. Quintiere, July 1990.

NIST 4348, "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 2: Characterization of Ignition Source and Comparable Gas Burner," T. Ohlemiller and K. Villa, June 1990.

NIST 4375, "Furniture Flammability: An Investigation of the California Technical Bulletin 133 Test — Part 3: Full-Scale Chair Burns," W. J. Parker, K. M. Tu, S. Nurbakhsh, and G. H. Damant, July 1990.

C-1.3 State of California Publication. State of California Department of Consumer Affairs, Bureau of Home Furnishings and Thermal Insulation.

California Technical Bulletin 129, *Flammability Test Procedure for Mattresses for Use in Public Buildings,* October 1992.

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