



Standard Test Method for Determining Particulate Matter Emissions from Wood Heaters¹

This standard is issued under the fixed designation E2780; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the fueling and operating protocol for determining particulate matter emissions from wood fires in wood-burning room heaters and fireplace inserts as well as determining heat output and efficiency.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

E631 Terminology of Building Constructions

E2515 Test Method for Determination of Particulate Matter Emissions Collected by a Dilution Tunnel

2.2 Other Standards:

ANSI/UL-103 Standard for Chimneys, Factory-Built, Residential Type and Building Heating Appliance

CSA B415.1 Performance Testing of Solid-Fuel-Burning Heating Appliances

3. Terminology

3.1 **Definitions**—Terms used in this test method are defined in Terminology **E631**.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 **burn rate, n** —the rate at which test fuel is consumed in a wood heater. Measured in kilograms (lb) (dry basis) per hour.

3.2.2 **combustion air control, n** —an air control device that regulates air to the wood heater that is primarily intended promote pyrolysis of the fuel load.

3.2.3 **Douglas fir, n** —untreated, standard, or better grade Douglas fir lumber with agency grade stamp: D. Fir or Douglas Fir.

3.2.4 **firebox, n** —the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.2.5 **fuel piece, n** — 2×4 or 4×4 wood pieces used to construct test fuel cribs and referring to the nominal width and depth dimensions for commonly available dimensional lumber. The actual dimensions are 38×89 mm ($1\frac{1}{2} \times 3\frac{1}{2}$ in.) and 89×89 mm ($3\frac{1}{2} \times 3\frac{1}{2}$ in.).

3.2.6 **fuel piece length, n** —the length of fuel pieces used to construct the test fuel crib measured in mm (in.).

3.2.7 **firebox height, n** —unless otherwise specified in the manufacturer's written instructions included with the heater, firebox height is the vertical distance extending above the loading door, if fuel could reasonably occupy that space, but not more than 2 inches above the top (peak height) of the loading door, to the floor of the firebox (i.e., below a permanent grate) if the grate allows a 1-inch diameter piece of wood to pass through the grate, or, if not, to the top of the grate. Firebox height is not necessarily uniform but must account for variations caused by internal baffles, air channels, or other permanent obstructions. A visible indicator or landmark within the firebox that will provide a clear indication to the heater user of the maximum height that fuel should be loaded, and is specifically referenced in the manufacturer's written instructions, may be used to determine firebox height for the purposes of calculating usable firebox volume.

3.2.8 **firebox length, n** —the longest horizontal fire chamber dimension where fuel pieces might reasonably be expected to be placed in accordance with the manufacturer's written instructions that is parallel to a wall of the chamber.

3.2.9 **firebox width, n** —the shortest horizontal fire chamber dimension where fuel pieces might reasonably be expected to be placed in accordance with the manufacturer's written instructions that is parallel to a wall of the chamber.

3.2.10 **kindling, n** —wood pieces used to initiate combustion of the pre-burn fuel. Kindling may be ignited using crumpled newspaper.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.11 *manufacturer's written instructions, n*—specific information regarding the fueling and operation procedures recommended by the heater manufacturer and included with the heater. These instructions must be consistent with information provided to the heater end-user in the owner's manual or equivalent.

3.2.12 *owner's manual, n*—written information provided to the heater end-user regarding the installation and recommended fueling and operating procedures that will help the heater user to achieve the best heater performance. It is also referred as the installation and operation guide or other equivalent title.

3.2.13 *particulate matter (PM), n*—all gas-borne matter resulting from combustion of solid fuel, as specified in this test method, which is collected in accordance with Test Method E2515.

3.2.14 *pre-burn fuel, n*—wood pieces used to pre-heat the wood heater and establish a charcoal bed prior to the test run.

3.2.15 *secondary combustion air control, n*—an air control device that regulates air to the wood heater that is primarily intended to provide the additional oxygen needed to promote secondary combustion of the combustible materials released during pyrolysis of the fuel load.

3.2.16 *test facility, n*—the area in which the wood heater is installed, operated, and sampled for emissions.

3.2.17 *test fuel crib, n*—the arrangement of the test fuel pieces and test fuel spacers.

3.2.18 *test fuel density, n*—the dry basis density of the test fuel pieces that comprise the test fuel crib.

3.2.19 *test fuel loading density, n*—the weight of the as-fired test fuel crib per unit volume of usable firebox.

3.2.20 *test fuel pieces, n*—the individual fuel pieces (nominal 2 × 4 and 4 × 4 dimensional lumber) that comprise the test fuel crib.

3.2.21 *test fuel spacers, n*—wood pieces used to space fuel pieces apart in the test fuel crib. Their function is to provide reproducible fuel crib geometry and air spaces between fuel pieces.

3.2.22 *test run, n*—an individual emission test which encompasses the time required to consume the mass of the test fuel crib.

3.2.23 *test series, n*—a group of test runs on the same wood heater.

3.2.24 *usable firebox volume, n*—the volume of the firebox determined using its height, length, and width as defined in this section.

3.2.25 *wood heater, n*—an enclosed, wood burning appliance capable of and intended for space heating and/or domestic water heating.

4. Summary of Test Method

4.1 This test method is used in conjunction with Test Method E2515. The wood heater under evaluation is fueled with kindling, pre-burn fuel and a test fuel load. Each test run is a hot-to-hot cycle. Individual test runs are conducted at burn rates ranging from low to maximum burn rates. The fuel load configuration is determined based on the usable firebox volume of the heater plus the firebox dimensions and geometry. Kindling and crumpled newspaper are used to ignite a pre-burn

fuel load(s) that is burned to heat the wood heater to normal operating temperature and to establish a charcoal bed. The test fuel load is placed on the charcoal bed and given time to ignite before the air control(s) is (are) set to the test run condition. When the full weight of the test fuel load has been burned, the test run is terminated. Burn rate is determined based on the weight of the test fuel load divided by the length of test run and corrected to a dry fuel basis. Particulate sampling begins before the test fuel load is added and stops when the test run terminates. The total particulate emissions are determined over the test run length. The particulate emissions rate is then determined from the total particulate emissions divided by the length of the test run and is reported in grams of particulate per hour. The particulate emission factor may also be determined from the total particulate emissions divided by the dry basis weight of the test fuel load and is reported in grams of particulate per dry kilogram of fuel. This test method may also be used in conjunction with CSA B415.1 for determining heat output and efficiency. If heat output is determined, particulate emissions per unit of heat delivered may also be calculated and is reported in grams of particulate per megajoule.

5. Significance and Use

5.1 This test method is used for determining emission rates and emission factors for wood heaters.

5.1.1 The emission factor is useful for determining emission performance during product development.

5.1.2 The emission factor is useful for the air quality regulatory community for determining compliance with emission performance limits.

5.1.3 The emission rate may be useful for the air quality regulatory community for determining impacts on air quality from wood heaters.

5.2 The reporting units are grams of particulate per hour, grams of particulate per kilogram of dry fuel and grams of particulate per megajoule of heat output.

5.2.1 Appropriate reporting units for comparing emissions from all types of solid fuel fired appliances: g/kg.

5.2.2 Appropriate reporting units for predicting atmospheric emission impacts: g/h or g/MJ.

5.3 The fuel load specified in this test method is a lumber crib of uniform dimensions, identical to that specified in EPA Method 28. Cribbers were specified in EPA Method 28 to provide a reproducible and repeatable test method. In normal operation the majority of fuel used by consumers is cordwood with irregular shapes and dimensions. Very little data exists to indicate whether or not the fuel cribs specified in this standard yield results that are predictive of performance using cordwood fuel. This standard, therefore, includes Annex A1 which provides a fueling procedure using cordwood. It is provided so that those interested in measuring emissions performance with cordwood will have a consistent method to follow. A comparative database using the two fueling procedures will provide data to determine whether test results using crib fuel correlate to test results using cordwood fuel.

6. Safety

6.1 *Disclaimer*—This test method may involve hazardous materials, operations, and equipment. This test method may not

address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7. Equipment and Supplies

7.1 Wood Moisture Meter—Calibrated electrical resistance meter capable of measuring test fuel moisture to within 1 % moisture content. Must meet the calibration requirements specified in 8.1.

7.2 Test Fuel Scale—A scale capable of weighing test fuel to within 0.005 kg (0.01 lb). Must meet the calibration requirements specified in 8.3.

7.3 Platform Scale—A scale capable of weighing the test wood heater and attached chimney, including the weight of the test fuel, to within 0.05 kg (0.1 lb). Must meet the calibration requirements specified in 8.2.

7.4 Wood heater Flue Gas Temperature Measurement Device—A 3.2 mm (0.125 in.) diameter sheathed, non-isolated junction Type K thermocouple capable of measuring flue gas temperature with an accuracy of 2.2°C (4.0°F) or 0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 8.4.

7.5 Wood Heater Surface Temperature Measuring Device—A temperature sensor capable of measuring surface temperatures with an accuracy of 2.2°C (4.0°F) or 0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 8.4.

7.6 Catalytic Combustor Exit Temperature Measuring Device—A temperature sensor capable of measuring the temperature of the gases exiting the catalytic combustor in a catalyst equipped heater with an accuracy of 2.2°C (4.0°F) or 0.75 % of the reading, whichever is greater. Must meet calibration requirements specified in 8.4.

7.7 Insulated Solid Pack Chimney—Chimney used for installation of wood heater in the test facility. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid pack insulating material surrounding the entire flue and possess a label demonstrating conformance to ANSI/UL-103, Standard for Chimneys, Factory-Built, Residential Type and Building Heating Appliance.

8. Calibration and Standardization

8.1 Wood Moisture Meter—Calibrate as in accordance with the manufacturer's instructions before each certification test.

8.2 Platform Scale—Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the test wood heater in place by weighing at least one calibration weight (ASTM Class F) that corresponds to between 20 and 80 % of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.05 kg (0.1 lb) or 1 % of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

8.3 Test Fuel Scale—Perform a multipoint calibration (at least five points spanning the operational range) of the test fuel scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (ASTM Class F) that corresponds to between 20 and 80 % of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.005 kg (0.01 lb) or 1 % of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

8.4 Temperature Sensors—Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall be in compliance with National Institute of Standards and Technology (NIST) Monograph 175, Standard Limits of Error.

9. Procedure

9.1 Pre-conditioning of the Wood Heater—The wood heater must be pre-conditioned before a test series begins.

9.1.1 Set up the wood heater in accordance with instructions provided by the manufacturer. The total height of chimney when measured from the floor or top of the platform scale shall be 4.6 ± 0.3 m (15 ± 1 ft).

9.1.2 Install a flue-gas temperature measurement device at the center of the flue, 2.6 ± 0.15 m (8.5 ± 0.5 ft) above the floor or top of the platform scale. For catalyst-equipped heaters, install a catalytic combustor exit temperature measurement device at the centroid of the catalytic combustor exit face and within 25 mm (1 in.) downstream of the catalytic combustor exit face.

9.1.3 Operate the wood heater for at least 48 hours at a medium burn rate as defined in 9.5.1 using fuel meeting the specifications in 9.4 or with any type of untreated wood with a moisture content between 15 and 25 % wet basis. The hours of operation do not need to be continuous.

9.1.4 Record the time and weight for all fuel added.

9.1.5 Record the flue-gas temperature at least once during each hour of operation.

9.1.6 For catalyst-equipped wood heaters, record the hourly catalytic combustor exit temperature.

9.1.7 Allow the wood heater to cool to room temperature and remove all unburned wood, charcoal, ash, or other debris from the firebox.

9.1.8 Clean the chimney using a standard chimney brush appropriately sized for the chimney.

9.2 Install the wood heater in the test facility.

9.2.1 Set up the wood heater in accordance with instructions provided by the manufacturer. Place the wood heater centrally on the platform scale. The venting shall consist of single wall pipe extending to 2.4 ± 0.1 m (8 ± 0.3 ft) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 4.6 ± 0.3 m (15 ± 1 ft) above the platform scale, and of the size specified by the wood heater manufacturer. This applies to both freestanding and fireplace insert type wood heaters. Do not install a chimney cap.

9.2.1.1 Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the wood heater

manufacturer's written appliance specifications require such chimney for home installation.

NOTE 1—The chimney that is used for testing should be documented in the test data and test report.

9.2.2 Locate wood heater surface temperature measuring devices at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, on two sidewall surfaces, and on the bottom and back surfaces. Position the monitor sensing tip on the firebox exterior surface inside of any heat shield, air circulation walls, or other wall or shield separated from the firebox exterior surface.

9.2.3 Center the flue outlet (chimney) under the dilution tunnel hood. Refer to Test Method **E2515** for specific requirements including positioning the flue outlet to meet induced draft and smoke capture requirements.

9.2.4 Install a flue-gas temperature measurement device at the center of the flue, 2.6 ± 0.15 m (8.5 ± 0.5 ft) above the top of the platform scale.

9.3 Usable Firebox Volume Determination:

9.3.1 Determine the firebox volume using the definitions for firebox height, width, and length in Section 3. Follow the manufacturer's written instructions that are included with the wood heater for specific recommendations to consumers for where fuel should or should not be placed in the firebox when determining usable firebox volume.

9.3.1.1 In the absence of specific written instructions regarding the placement of fuel in the firebox, take into account reasonable consumer loading practices. Guidelines for usable firebox volume adjustments due to the presence of firebrick and other permanent fixtures are as follows:

(1) Adjust width and length dimensions to extend to the metal wall of the wood heater above the firebrick or permanent obstruction if the firebrick or obstruction extending the length of the side(s) or back wall extends less than one third of the usable firebox height. Use the width or length dimensions inside the firebrick if the firebrick extends more than one third of the usable firebox height.

(2) If a log retainer or grate is a permanent fixture and the manufacturer recommends that no fuel be placed outside the retainer, the area outside of the retainer is excluded from the firebox volume calculations.

(3) Include areas adjacent to and above a baffle (up to two inches above the fuel loading opening) if four inches or more horizontal space exist between the edge of the baffle and a vertical obstruction (e.g., sidewalls or air channels).

9.4 Fuel:

9.4.1 Fuel Properties:

9.4.1.1 Fuel Species—The fuel is untreated, standard, or better grade certified Douglas fir lumber.

9.4.1.2 Fuel Moisture—The fuel moisture shall be measured using a fuel moisture meter as specified in 7.1. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 100°F. Fuel moisture shall be measured within four hours of using the fuel for a test.

NOTE 2—It has been found that to maintain fuel within the allowable moisture content range storage at a relative humidity of 95 % or higher

and temperature of 90 to 100°F is necessary. In addition, storage at these conditions for a period of several weeks results in relatively uniform moisture content throughout the fuel pieces and thus improves the accuracy of the moisture content measurement.

(1) **Test Fuel Piece Moisture**—The average fuel moisture for each test fuel piece used to construct the test fuel cribs (excluding test fuel spacers) shall be between 19 and 25 % dry basis. Kiln-dried lumber is not permitted. Determine the fuel moisture for each test fuel piece used for the test fuel crib by averaging at least three fuel moisture meter readings, one from each of three sides, measured parallel to the wood grain. If an electrical resistance type fuel moisture meter is used, penetration of insulated electrodes shall be $\frac{1}{4}$ the thickness of the fuel piece or 19 mm ($\frac{3}{4}$ in.), whichever is greater.

(2) **Test Fuel Spacer Moisture**—Determine fuel moisture for each test fuel spacer. One moisture meter reading from each spacer, measured parallel to the wood grain is sufficient. If an electrical resistance type fuel moisture meter is used, penetration of insulated electrodes shall be $\frac{1}{4}$ the thickness of the spacers. Average all the readings for all the test fuel spacers to determine the average test fuel spacer moisture.

9.4.1.3 Test Fuel Density—The average test fuel density, dry basis, shall be in the range of 401 to 578 kg/m³ (25 to 36 lb/ft³) for the test fuel cribs. Nails and test fuel spacers are excluded from the density determinations. Determine the total volume of the fuel pieces that comprise the test fuel crib. Use the wet basis weight and the arithmetically averaged dry basis moisture content to determine the dry basis weight for the individual fuel pieces. Determine dry basis weight for the test fuel pieces that comprise the test fuel crib (excluding nails and spacers) by summing the dry basis weight of the individual fuel pieces that comprise the crib. Divide the dry basis weight by the volume to determine the density.

9.4.1.4 Fuel Temperature—The test fuel temperature shall be within the allowable test facility temperature range as in accordance with Test Method **E2515**. The fuel temperature may be determined by measuring the temperature of the room where the test fuel has been stored for at least 24 hours prior to the fuel moisture determination.

9.4.1.5 The test fuel crib loading density shall be 112 ± 11.2 kg/m³ (7 ± 0.7 lb/ft³) of usable firebox volume on a wet basis.

9.4.1.6 Fuel Dimensions—The cross-sectional dimensions of each test fuel piece shall conform to the nominal measurements of 2×4 and 4×4 lumber. Each test fuel piece (not including spacers) shall be of equal length, except as provided in 9.4.1.10, and shall closely approximate $\frac{5}{8}$ the dimensions of the firebox length. Alternatively, the shape of the test fuel crib may be geometrically similar to the shape of the firebox volume without resorting to special angular or round cuts on the individual fuel pieces.

(1) The fuel piece composition of the test fuel crib shall be determined in relation to the appliance's firebox volume according to guidelines listed below:

(a) If the usable firebox volume is less than or equal to 0.043 m³ (1.5 ft³), use only 2×4 lumber.

(b) If the usable firebox volume is greater than 0.043 m³ (1.5 ft³) and less than or equal to 0.085 m³ (3.0 ft³), use 2×4 and 4×4 lumber. From 35 to 65 % of the weight of the

test fuel crib including spacers shall be 2×4 lumber and the remainder shall be 4×4 lumber.

(c) If the usable firebox volume is greater than 0.085 m^3 (3.0 ft^3), use only 4×4 lumber.

(2) *Test Fuel Spacer*—The test fuel spacers shall be $130 \times 40 \times 20 \text{ mm}$ ($5 \times 1.5 \times 0.75 \text{ in.}$).

9.4.1.7 *Nails*—Use uncoated, un-galvanized nails for assembling the attaching test fuel spacers to the test fuel pieces. The number of nails used should be limited to the minimum number necessary to hold the test fuel spacers to the test fuel pieces.

9.4.1.8 *Test Fuel Crib Weight (dry basis)*—Determine the total dry basis fuel weight by summing the dry basis weight of the individual test fuel pieces and combined dry basis weight of the test fuel spacers that comprise the test fuel crib (without nails).

9.4.1.9 Attach the test fuel spacers to the test fuel pieces with nails in accordance with 9.4.1.7 as illustrated in Fig. 1. Attachment of test fuel spacers to the top of the test fuel piece(s) that comprise the top layer of the test fuel crib is optional.

9.4.1.10 To avoid stacking difficulties, or when a whole number of test fuel pieces does not result, all piece lengths shall be adjusted uniformly to remain within the specified loading density.

9.4.1.11 *Test Fuel Crib Weight (wet basis)*—Record the total weight (wet basis) of the test fuel crib after it is assembled (including nails and spacers) using the test fuel scale specified in 8.3. The weighed test fuel crib must be used within 3 h of being weighed.

9.5 Burn Rates:

9.5.1 *Burn Rate Categories*—One emission test run is required in each of the following burn rate categories:

9.5.1.1 *Maximum Burn Rate*—For the Maximum Category, the wood heater shall be operated with the combustion air control(s) set to achieve the maximum possible burn rate

TABLE 1 Burn Rate Categories

Average kg/h (lb/h), Dry Basis		
Low	Medium	Maximum
0.60 ^A to 1.15 (1.32 ^A to 2.54)	1.16 to 1.75 (2.55 to 3.86)	Maximum burn rate

^A Burn rates $< 0.6 \text{ kg/h}$ (1.32 lb/h) are allowed but not required.

TABLE 2 Alternative Burn Rate Categories

% of Maximum Burn Rate		
Low	Medium	Maximum
18 ^A to 35	36 to 53	100

^A Burn rates $< 18 \%$ of maximum are allowed but not required.

during the entire test run (or, if thermostatically controlled, the thermostat shall be set at maximum heat output setting at the start of the test run and shall be allowed to operate normally during the test run).

9.5.1.2 Other Burn Rate Categories:

(1) For burn rates in the low category, the combustion air control(s) or other mechanical control device shall be set at the minimum operating setting(s) other than fully off. The minimum operating setting(s) is the lowest possible operating position(s) or at the combustion air control stop, whichever is applicable. If the resultant burn rate is less than 0.6 kg/h (1.32 lb/h) when using Table 1 or less than 18 % of the maximum burn rate when using Table 2, the test run may be replaced with a test run with a burn rate that is less than or equal to 0.8 kg/h (1.76 lb/h) when using Table 1 or less than 24 % of the maximum burn rate when using Table 2. Results from any test run conducted at a burn rate below the minimum burn rate range as defined in Table 1 or Table 2, as applicable, shall be reported or but need not be included in the test run weighted average provided that such results are replaced with results from a test run meeting the criteria above.

(2) For test runs in the medium category, the wood heater shall be operated with the combustion air control(s), or other

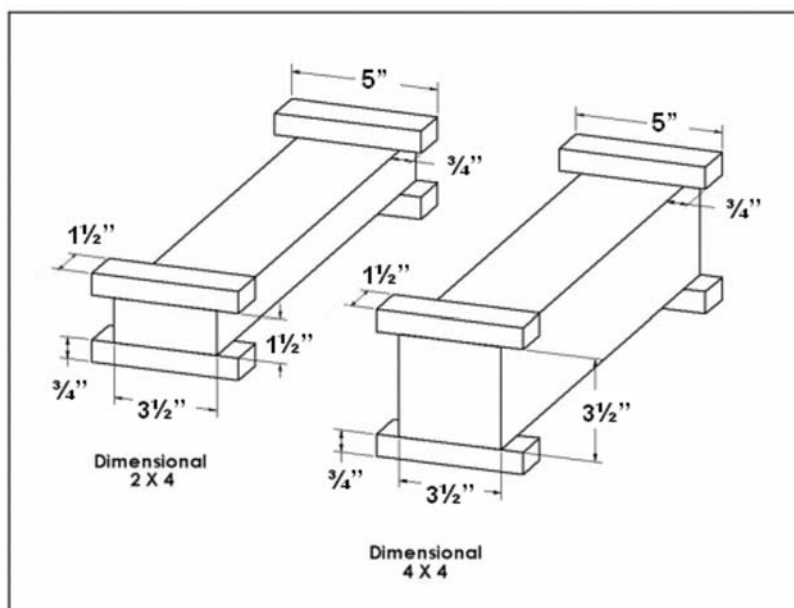


FIG. 1 Test Fuel Spacer Attachment

mechanical control device, set at a predetermined position necessary to obtain the average burn rate required for the category.

(3) For heaters with automatic controls, the controls may be allowed to function in a manner consistent with the owner's manual and with normal operation in a home as long as the required burn rate categories in accordance with 9.5.1 are achieved. The test laboratory shall document the procedures used to achieve the burn rates.

(4) The results from test runs that fall above the definition of the medium burn rate category in accordance with Table 1 or Table 2 shall be included with the medium category test results when determining the average emissions in accordance with Section 10.

9.5.1.3 If a wood heater tested using Table 1 cannot be operated at a burn rate below 1.15 kg/h (2.54 lb/h), the flue shall be dampered in order to achieve one average burn rate test run at or below 1.15 kg/h. Additionally, if flue dampering must be used to achieve a burn rate below 1.15 kg/h, results from any test run conducted at a burn rate below 1.00 kg/h need not be reported or included in the test run weighted average provided that such results are replaced with results from a test run meeting the criteria above.

(1) Evidence that a wood heater cannot be operated at a burn rate less than 1.15 kg/h shall include documentation of two or more test runs demonstrating that the burn rates were above 1.15 kg/h when the combustion air control(s) were adjusted to the lowest operating setting(s) in accordance with 9.5.1.2(1).

9.5.1.4 If a wood heater tested using Table 2, cannot be operated at a burn rate below 35 % of the maximum burn rate, the flue shall be dampered in order to achieve one average burn rate test run at or below 35 % of the maximum burn rate. Additionally, if flue dampering must be used to achieve burn rates below 35 % of the maximum burn rate results from any test run conducted at a burn rate below 25 % of the maximum burn rate need not be reported or included in the test run weighted average provided that such results are replaced with results from a test run meeting the criteria above.

(1) Evidence that a wood heater cannot be operated at a burn rate less than 35 % of the maximum burn rate shall include documentation of two or more test runs demonstrating that the burn rates were above 35 % of the maximum burn rate when the combustion air control(s) were adjusted to the lowest possible operating setting(s) in accordance with 9.5.1.2(1).

9.5.2 *Pre-burn Ignition*—Build a fire in the wood heater in accordance with the manufacturer's written instructions.

9.5.2.1 *Pre-burn Fuel Charge*—Crumpled newspaper and kindling may be used to help ignite the pre-burn fuel. The pre-burn fuel, used to sustain the fire and establish the pre-test run charcoal bed, shall meet the same fuel requirements prescribed in 9.4.

9.5.3 *Wood Heater Operation and Adjustments*—Set the combustion air control(s) at any position that will maintain combustion of the pre-burn fuel load. At least one hour before the start of the test run, set the combustion air control(s) at the approximate positions necessary to achieve the burn rate desired for the test run. Adjustment of the combustion air

control(s), fuel addition or subtractions, and coal bed raking shall be kept to a minimum but are allowed up to 15 minutes prior to the start of the test run. For the purposes of this method, coal bed raking is the use of a metal tool (poker) to stir coals, break burning fuel pieces into smaller pieces, dislodge fuel pieces from positions of poor combustion, and check for the condition of uniform charcoalization. Record all adjustments made to the combustion air control(s), adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during pre-burn ignition period. Record fuel weight data and wood heater temperature measurements at 10 minute intervals during the hour of the pre-burn ignition period preceding the start of the test run. During the 15-minute period prior to the start of the test run, the wood heater loading door shall not be open more than a total of 1 minute. Coal bed raking is the only adjustment allowed during this period.

NOTE 3—One purpose of the pre-burn ignition period is to achieve uniform charcoalization of the test fuel bed prior to loading the test fuel crib. Uniform charcoalization is a general condition of the test fuel bed evidenced by an absence of large pieces of burning wood in the coal bed and the remaining fuel pieces being brittle enough to be broken into smaller charcoal pieces with a metal poker. Manipulations to the fuel bed prior to the start of the test run should be done to achieve uniform charcoalization while maintaining the desired burn rate. In addition, some wood heaters (e.g., high mass units) may require extended pre-burn burn time and fuel additions to reach an initial average surface temperature sufficient to meet the thermal equilibrium criteria in 9.5.10.

9.5.4 The weight of pre-burn fuel remaining at the start of the test run is determined as the difference between the weight of the wood heater with the remaining pre-burn fuel and the tare weight of the cleaned, dry wood heater with or without dry ash or sand added consistent with the manufacturer's instructions and the owner's manual. The tare weight of the wood heater must be determined with the wood heater (and ash, if added) in a dry condition.

9.5.5 *Test Run Start:*

9.5.5.1 When the kindling and pretest fuel have been consumed to leave a pre-test charcoal bed weight between 20 and 25 % of the weight of the test fuel crib (wet basis), record the weight of the fuel remaining and start the test run. Record all wood heater individual surface temperatures, catalyst temperature if applicable, any initial sampling method measurement values, and begin the particulate emission sampling in accordance with Test Method E2515. Within 1 minute following the start of the test run, open the wood heater door, load the test fuel crib, and record the test fuel crib weight. Recording of the average, rather than individual, surface temperatures is acceptable.

9.5.5.2 Unless a different fuel loading orientation is recommended in the manufacturer's written instructions, position the fuel crib so that the spacers are parallel to the floor of the firebox, with the spacer edges abutting each other. If loading difficulties result, some fuel pieces may be placed on edge. If the usable firebox volume is between 0.043 and 0.085 m³ (1.5 and 3.0 ft³), alternate the piece sizes in vertical stacking layers to the extent possible. For example, place 2 × 4's on the bottom layer in direct contact with the coal bed and 4 × 4's on the next layer, etc. (see Fig. 1). Position the fuel pieces parallel

to each other and parallel to the longest wall of the firebox to the extent possible within the specifications in 9.4.

9.5.5.3 Load the test fuel crib in appliances having unusual or unconventional firebox design maintaining air space intervals between the test fuel pieces and in conformance with the manufacturer's written instructions. For any appliance that will not accommodate the loading arrangement specified in the paragraph above, document the test fuel crib arrangement used including the rationale for the fuel piece placement.

9.5.5.4 *Load Time*—The maximum allowable time for loading the test fuel into the wood heater is equal to 1060 s/m³ (30 s/ft³) of usable firebox volume as determined in accordance with 9.3.

9.5.5.5 *Start-up Time*—The wood heater door may remain open and the combustion air control(s) adjusted for up to 5 minutes after the maximum load time in accordance with 9.5.5.4 has lapsed in order to make adjustments to the test fuel crib and to ensure ignition of the test fuel crib has occurred. Within the 5 minute start-up time, close the wood heater door(s) and adjust the combustion air control(s) to the position determined to produce the desired burn rate. No other adjustments to the combustion air control(s) or the test fuel crib are allowed (except as specified in 9.5.7 and 9.5.8) after the five minutes of start-up time has elapsed. Record the length of time the wood heater door remains open, the adjustments to the combustion air control(s), and any other operational adjustments.

9.5.6 *Data Recording*—Record all data at intervals no greater than 10 minutes, including fuel weight data, wood heater individual surface and catalyst temperature measurements, other wood heater operational data (e.g., draft), test facility temperature and Test Method E2515 data.

9.5.7 *Test Fuel Crib Adjustment*—The test fuel crib pieces may be adjusted (i.e., repositioned) once during a test run if more than 60 % of the initial test fuel crib weight has been consumed and more than 10 minutes have elapsed without a measurable (< 0.05 kg (0.1 lb) or 1.0 %, whichever is greater) weight change. The time used to make this adjustment shall be less than 15 seconds.

9.5.8 *Air Control(s) Adjustment*—Secondary combustion air control(s) may be adjusted once during the test run following the manufacturer's written instructions. No other air control(s) adjustments are allowed during the test run.

9.5.9 *Test Run Completion*—The test run is completed when the remaining weight of the test fuel charge is 0.00 kg (0.0 lb). End the test run when the scale has indicated a test fuel charge weight of 0.00 kg (0.0 lb) or less for 30 seconds. At the end of the test run, stop the particulate sampling, and record the final fuel weight, the run time, and all final measurement values.

9.5.10 *Wood Heater Thermal Equilibrium*—The average of the wood heater surface temperatures at the end of the test run shall agree with the average surface temperature at the start of the test run to within 70°C (126°F) or the test run is invalid. Alternatively, the wood heater thermal equilibrium criteria in 10.3 may be used to determine test validity.

9.5.11 *Auxiliary Wood Heater Equipment Operation*—Heat exchange blowers sold with the wood heater shall be operated during the test run following the manufacturer's written

instructions. In the absence of manufacturer's written instructions, operate the heat exchange blower in the "high" position. (Automatically operated blowers shall be operated as designed.) Shaker grates, by pass controls, or other auxiliary equipment may be adjusted only one time during the test run following the manufacturer's written instructions. Record all adjustments on a wood heater operational written record.

NOTE 4—If the wood heater is sold with a heat exchange blower as an option, test the wood heater with the heat exchange blower operating as described in 9.5.1 through 9.5.10 and report the results. As an alternative to repeating all test runs without the heat exchange blower operating, one additional test run shall be conducted without the blower operating as described in 9.5.9 at a burn rate in the Medium Category (see 9.5.1). If the emission rate resulting from this test run without the blower operating is equal to or less than the emission rate plus 1.0 g/h (0.0022 lb/h) for the test run in the Medium burn rate Category with the blower operating, the wood heater may be considered to have the same average emission rate with or without the blower operating. Additional test runs without the blower operating are unnecessary.

9.5.12 *Consecutive Test Runs*—Test runs on a wood heater may be conducted consecutively provided that a minimum one hour interval occurs between test runs.

9.5.13 *Additional Test Runs*—The testing laboratory may conduct more than one test run in each of the burn rate categories specified in 9.5.1. If more than one test run is conducted at a specified burn rate, the results from at least two thirds of the test runs in that burn rate category shall be used in calculating the weighted average emission rate (see 10.2). The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the weighted average emission rate.

10. Data Analysis and Calculations

10.1 Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

10.2 Nomenclature:

$$M_{Sdb} = (M_{Swb}) (100/(100 + FM_S)) \quad (1)$$

where:

FM_S = average fuel moisture of all test fuel spacers, % dry basis,

M_{Swb} = weight of all test fuel spacers, wet basis, kg (lb), and

M_{Sdb} = weight of all test fuel spacers, dry basis, kg (lb).

$$M_{Cdb} = \sum (M_{CPnwb}) (100/(100 + FM_{CPn})) \quad (2)$$

where:

M_{CPnwb} = weight of each test fuel piece n in fuel crib, excluding nails and spacers, wet basis, kg (lb),

M_{Cdb} = weight of fuel crib, excluding nails and spacers, dry basis, kg (lb),

FM_{CPn} = average fuel moisture of test fuel piece n in fuel crib, % dry basis, and

n = individual test fuel pieces that comprise the test fuel crib, as applicable.

$$D_{Cdb} = M_{Cdb}/V_C \quad (3)$$

where:

D_{Cdb} = density of fuel crib, excluding spacers and nails, dry basis, kg/m³ (lb/ft³), and
 V_C = volume of fuel crib, m³ (ft³).

$$M_{FTAdb} = M_{Sdb} + M_{Cdb} \quad (4)$$

where:

M_{FTAdb} = total weight of fuel crib excluding nails, dry basis, kg (lb).

$$BR = \frac{60 M_{FTAdb}}{\theta} \quad (5)$$

where:

BR = dry burn rate, kg/h (lb/h), and
 θ = total length of test run, min.

$$PM_R = 60(E_T/\theta) \quad (6)$$

where:

E_T = total particulate emissions for test run from Test Method E2515, g (lb),
 θ = total length of test run, min, and
 PM_R = particulate emission rate for test run, g/h.

$$PM_F = E_T/M_{FTAdb} \quad (7)$$

where:

PM_F = particulate emission factor for test run, g/dry kg of fuel burned.

$$PM_H = E_T/E_O \quad (8)$$

where:

E_O = average measured overall heat output over the test run from Annex A2, MJ (MMBtu), and
 PM_H = average particulate emissions per unit of average heat output over the test run, g/MJ (lb/MMBtu).

$$PM_{Rw} = 0.4(PM_{RLAve}) + 0.4(PM_{RMAve}) + 0.2(PM_{RHAve}) \quad (9)$$

where:

PM_{RLAve} = arithmetic average emission rate for all test runs (except in accordance with 9.5.13) that are included in the Low Burn Rate Category, g/h (lb/h),
 PM_{RMAve} = arithmetic average emission rate for all test runs (except in accordance with 9.5.13) that are included in the Medium Burn Rate Category, g/h (lb/h),
 PM_{RHAve} = arithmetic average emission rate for all test runs (except in accordance with 9.5.13) are included in the High Burn Rate Category, g/h (lb/h), and
 PM_{Rw} = weighted average emission rate, g/h (lb/h).

$$PM_{Hw} = 0.4(PM_{HLAve}) + 0.4(PM_{HMAve}) + 0.2(PM_{HHAve}) \quad (10)$$

where:

PM_{HLAve} = arithmetic average emissions per heat output unit for all test runs (except in accordance with 9.5.13) that are included in the Low Burn Rate Category, g/MJ (lb/MMBtu),

PM_{HMAve} = arithmetic average emissions per heat output unit for all test runs (except in accordance with 9.5.13) that are included in the Medium Burn Rate Category, g/MJ (lb/MMBtu),
 PM_{HHAve} = arithmetic average emissions per heat output unit for all test runs (except in accordance with 9.5.13) that are included in the High Burn Rate Category, g/MJ (lb/MMBtu), and
 PM_{Hw} = weighted average emissions per heat output unit, g/MJ (lb/MMBtu).

$$\eta_{Ow} = 0.4(\eta_{OLAve}) + 0.4(\eta_{OMAve}) + 0.2(\eta_{OHAve}) \quad (11)$$

where:

η_{OLAve} = arithmetic average overall efficiency for all test runs (except in accordance with 9.5.13) that are included in the Low Burn Rate Category as determined in accordance with Annex A2, %,
 η_{OMAve} = arithmetic average overall efficiency for all test runs (except in accordance with 9.5.13) that are included in the Medium Burn Rate Category as determined in accordance with Annex A2, %, and
 η_{OHAve} = arithmetic average overall efficiency for all test runs (except in accordance with 9.5.13) that are included in the High Burn Rate Category as determined in accordance with Annex A2, %, and
 η_{Ow} = weighted average overall efficiency, %.

10.3 Wood Heater Thermal Equilibrium:

10.3.1 If the difference between the amount of heat stored in the mass of the test heater at the end of the test run versus the beginning of the test run (ΔQ_H) is greater than 8.5 % of the dry basis heat content of the test fuel crib (Q_{FC}), the test run shall be invalid. If $|\Delta Q_H| > 0.085(Q_{FC})$, the test run is invalid

$$\Delta Q_H = (0.5M_{Hm} + 0.83M_{Hr})(\Delta T_H) \quad (12)$$

where:

M_{Hm} = weight of the metallic portion of the heater assembly, kg,
 M_{Hr} = weight of the refractory portion of the heater assembly, kg, and
 ΔT_H = the difference in the average heater surface temperature from the start of the test run to the end of the test run, °C, and
 ΔQ_H = the difference between the amount of heat stored in the mass of the test heater at the end of the test run versus the beginning of the test run, KJ.

$$\Delta Q_H = (0.1M_{Hm} + 0.2M_{Hr})(\Delta T_H) \quad (13)$$

where:

M_{Hm} = weight of the metallic portion of the heater assembly, lb,
 M_{Hr} = weight of the refractory portion of the heater assembly, lb, and
 ΔT_H = the difference in the average heater surface temperature from the start of the test run to the end of the test run, °F, and.

ΔQH = the difference between the amount of heat stored in the mass of the test heater at the end of the test run versus the beginning of the test run, BTU.

$$Q_{FC} = (M_{FTAdb}) (H_{FC}), \quad (14)$$

where:

H_{FC} = heating value of fuel crib, dry basis, (BTU/lb) (refer to Annex A2 in this test method for additional information about heating value), and

Q_{FC} = the dry basis heat content of the test fuel crib KJ (BTU).

11. Precision and Bias

11.1 *Precision*—It is not possible to specify the precision of the procedure in this test method for measuring wood heater

emissions because the appliance operation and fueling protocols and the appliances themselves produce variable amounts of emissions and, therefore, the results cannot be used to determine reproducibility or repeatability of this measurement method.

11.2 *Bias*—No information can be presented on the bias of the procedure in this test method for measuring wood heater emissions because no material having an accepted reference value is available.

12. Keywords

12.1 emissions; particulate; particulate matter; wood-burning; wood heater; wood stove

ANNEXES

(Mandatory Information)

A1. CORDWOOD FUELING AND OPERATION

A1.1 Scope

A1.1.1 This annex to the test method covers fueling and operating protocol for determining particulate matter emissions from wood heaters using cordwood test fuel. The annex provides substitute requirements for cordwood operation. This annex is used in conjunction with all other applicable requirements of the test method. This annex may also be used in conjunction with Annex A2 when determining wood heater efficiency.

A1.2 Terminology

A1.2.1 *Definitions of Terms Specific to this Annex:*

A1.2.1.1 *cordwood test fuel, n*—conventional firewood, often referred to as “round wood,” although, in practice, it is usually round wood 300 to 600 mm (11.8 to 23.6 in.) long that has been split into segments. There is no equivalent SI term to the imperial volumetric measure of cord (4 ft × 4 ft × 8 ft = 128 ft³), as piled, including air space; the SI conversion factor is 3.624 556 m³/cord.

A1.2.1.2 *test run, n*—an individual emission test which encompasses the time required to consume the mass of the cordwood test fuel load.

A1.3 Equipment and Supplies (Same as Test Method)

A1.4 Calibration and Standardization (Same as Test Method)

A1.5 Cordwood Test Fuel

A1.5.1 *Fuel Properties:*

A1.5.1.1 *Fuel Species and Properties*—Test fuel charge fuel shall be species of cordwood with a specific gravity range of 0.60 to 0.73 (see Table A1.1 for examples of some fuel species that typically meet the specific gravity requirement. Other fuel species may be used if they meet the specific gravity require-

TABLE A1.1 Specific Gravity of Commercially Important Species of Wood Based on Oven-Dry Weight and Oven-Dry Volume

Species	Specific Gravity
Ash, white	0.63
Beech	0.67
Birch, sweet	0.71
Birch, yellow	0.65
Elm, rock	0.67
Maple, hard (black)	0.60
Maple, hard (sugar)	0.67
Oak, red	0.66
Oak, white	0.71
Pine, Southern, longleaf	0.64

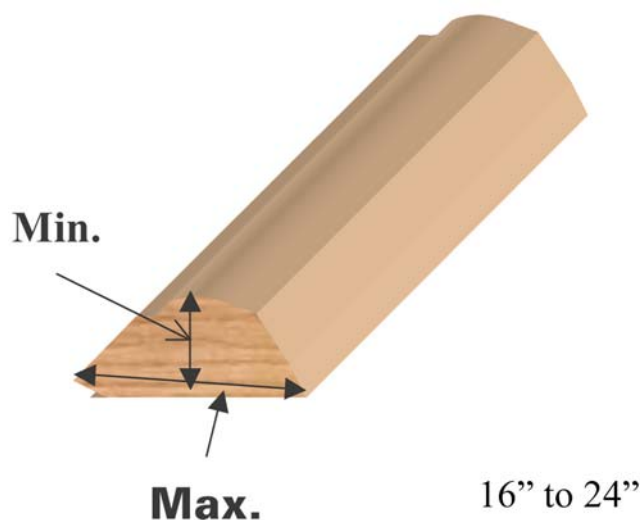


FIG. A1.1 Dimensions of Test Fuel Pieces

ment). Only cordwood pieces that are free of decay, fungus and loose bark shall be used.

TABLE A1.2 Correlation of Cordwood Wood Pieces with Appliance Firebox Volume^A

Firebox Volume m ³ (ft ³)	Cross Section Min/Max mm (in.)	Piece Min Weight kg (lb)	Piece Max Weight kg (lb)	80% Piece Weight Range kg (lb)	Number of Pieces
<0.113 (4.0)	51 (2.0) / 152 (6.0)	1 (2.2)	6 (13.2)	1.5 (3.3) – 5 (11.0)	4 – 7
0.113 (4.0) – 0.283 (10.0)	64 (2.5) / 203 (8.0)	2 (4.4)	8 (17.6)	3 (6.6) – 7 (15.5)	5 – 10
0.283 (10.0) – 0.566 (20.0)	76 (3.0) / 254 (10.0)	3 (6.6)	10 (22.0)	4 (8.8) – 9 (19.8)	8 – 15
>0.566 (20.0)	76 (3.0) / 305 (12.0)	4 (8.8)	12 (26.4)	4 (8.8) – 10 (22.0)	>12

^A Source: Wood Structural Design Data—National Forest Products Association

A1.5.1.2 Cordwood Test Fuel Moisture—The average cordwood test fuel piece moisture content shall be in the range of 18 to 28 % on a dry basis when tested in accordance with the following procedure.

NOTE A1.1—Once split cordwood pieces have dried to an average moisture content that is near the top of the allowable moisture content range, it has been found that to maintain the fuel pieces within the allowable moisture content range, storage at a relative humidity of 95 % or higher and temperature of 90 to 100°F is necessary. In addition, storage at these conditions for a period of several months helps achieve a more uniform moisture content throughout the fuel pieces and thus improves the accuracy of the moisture content measurement.

(1) Using a fuel moisture meter as specified in 7.1 of the test method, determine the fuel moisture for each cordwood test fuel piece used for the cordwood test fuel load by averaging at least three fuel moisture meter readings, one from each of three sides, measured parallel to the wood grain. Penetration of the moisture meter insulated electrodes shall be ¼ the thickness of the fuel piece or 19 mm (¾ in.), whichever is greater. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 100 °F. Fuel moisture shall be measured within four hours of using the fuel for a test.

A1.5.1.3 Cordwood Test Fuel Piece Length—Piece length shall be 508 ± 102 mm (20 ± 4 in) (see Fig. A1.1).

A1.5.2 Cordwood Test Fuel Loads—Test fuel loads shall be determined by multiplying the firebox volume by 4.54 kg (10 lb), or a higher load density as recommended by the manufacturers printed operating instructions, of wood (as used wet weight) per cubic foot. Test fuel loads shall be made up of fuel pieces as specified in Table A1.2. Select the number of pieces

of fuel that most nearly match this target weight. When the manufacturer’s written instructions specify fuel loading to a specific level, the firebox shall be loaded with fuel as specified in A1.5.5 to the level indicated and the weight of the fuel load recorded. This weight shall then be divided by the firebox volume as determined in 9.3 in the Test Method and the resulting loading density shall be reported. If this loading density is less than 162 kg/m³ (10 lb/ft³), all tests shall be run with fuel load densities of 162 kg/m³ (10 lb/ft³) even though this could require loading to a level higher than indicated in the manufacturer’s instructions.

A1.5.3 Pre-burn Fuel—The pre-burn fuel pieces shall be cordwood in approximately the same weight ratio as used for the test fuel load. Crumpled newspaper and kindling may be used to help ignite the pre-burn fuel.

A1.5.4 When the kindling and pre-burn fuel have been consumed to leave a pre-test fuel weight between 10 and 25 % of the weight of the test fuel load, record the weight of the fuel remaining and start the test run. Record all required data at the start of the test run. Load time and start-up time are as defined in 9.5.5.4 and 9.5.5.5 in the test method. Refer to other requirements in the test method as applicable and to the requirements of Test Method E2515.

A1.5.5 Test Fuel Piece Placement—Pieces are to be placed in the firebox parallel to the longest firebox dimension or in the direction specified in the manufacturer’s printed operating instructions. When loading test fuel loads, no effort shall be made to stack fuel pieces either tightly or loosely with respect to one another.

A2. WOOD HEATER THERMAL EFFICIENCY AND HEAT OUTPUT DETERMINATION

A2.1 Scope

A2.1.1 This annex to the test method covers the determination of overall efficiency and heat output for wood heaters.

A2.2 Referenced Documents

A2.2.1 Other Documents:

CSA B415.1 Performance Testing of Solid-Fuel-Burning Heating Appliances

An Atlas of Thermal Data for Biomass and Other Fuels (NREL/TP-433-7965)

The Energy Research Center of the Netherlands “PHYLLIS” database

A2.3 Summary of Test Method

A2.3.1 The procedures in this annex may be used in conjunction with the test method to allow determination of the overall thermal efficiency and the heat output for each test run. Literature values, rather than measured values are used for the calorific value and ultimate analysis for the fuel species used for testing. This annex may be used with crib test fuel or cordwood test fuel. Additionally, in conjunction with the test method, the results determined by the procedures in the annex may be used to determine the integrated average particulate emissions per delivered heat output for each test run, expressed in g/MJ (lb/MMBtu).

A2.4 Significance and Use

A2.4.1 This annex is used for determining the average thermal efficiency and heat output for wood heaters.

A2.4.2 This annex is used to determine the particulate emission rate per unit of heat delivered. This is useful when comparing different types of heating equipment.

A2.4.3 Due to the variability from piece to piece within a given test fuel load, the uncertainty in whether fuel properties determined using ASTM sampling and test methods are actually representative of the average fuel properties of the entire test fuel load has resulted in the use of literature values for the properties (other than moisture content) of the fuel in the calculation of overall efficiency and heat output. The literature values are based on average values reported in scientific literature and in international data bases. **Table A2.1** provides this data for some common fuel wood species. This data is taken from “An Atlas of Thermal Data for Biomass and Other Fuels” (NREL/TP-433-7965) and the Energy Research Center of the Netherlands “PHYLLIS” database. If species not listed in **Table A2.1** are used for testing, average values for the fuel properties (other than moisture content) reported in scientific literature or in international databases should be used.

A2.5 Procedure

A2.5.1 The procedures used in the annex shall be in accordance with Clauses 6.2.1, 6.2.2, 6.3, 10.4.3 (a), 10.4.3(f-j), and 13.7 of **CSA B415.1**, 3rd Edition, 2010.

A2.5.1.1 Measure and record the test room air temperature in accordance with the requirements of **CSA B415.1**, Clauses 6.2.1 and 10.4.3 (g).

A2.5.1.2 Measure and record the flue gas temperature in accordance with the requirements of **CSA B415.1**, Clauses 6.2.2 and 10.4.3 (f).

A2.5.1.3 Determine and record the Carbon Monoxide (CO) and Carbon Dioxide (CO₂) concentrations in the flue gas in accordance with **CSA B415.1**, Clauses 6.3 and 10.4.3 (i) and (j).

A2.5.1.4 Measure and record the test fuel weight in accordance with the requirements of **CSA B415.1**, Clause 10.4.3 (h).

A2.5.1.5 Record the test run time in accordance with the requirements of **CSA B415.1**, Clause 10.4.3 (a).

A2.6 Data Analysis and Calculations

A2.6.1 Thermal Efficiency and Heat Output:

A2.6.1.1 For determination of the average thermal efficiency and average heat output for the test run, use the data collected over the full test run and the calculations in accordance with **CSA B415.1**, Clause 13.7 except for 13.7.2 (d), (e), (f), and (g), use the fuel properties in accordance with **Table A2.1** for the fuel species used for testing.

A2.6.2 Nomenclature:

E_O = average measured overall heat output over the test run, MJ (MMBtu/h), and

η_r = overall efficiency for the test run, %.

APPENDIX

(Nonmandatory Information)

X1. SINGLE BURN RATE APPLIANCE FUELING AND OPERATION

X1.1 Scope

X1.1.1 This annex to the test method covers fueling and operating protocol for determining particulate matter emissions from wood heaters that have non-adjustable combustion air control(s). This annex is used in conjunction with all other applicable requirements of the test method. This annex may

also be used in conjunction with **Annex A2** when determining wood heater efficiency.

X1.2 Terminology

X1.2.1 Definitions of Terms Specific to this Annex:

TABLE A2.1 Fuel Properties by Fuel Species

Species	%C	%H	%O	%Ash	HHV	
					MJ/kg	Btu/lb
Ash, white	49.7	6.9	43	0.3	20.75	8927
Beech	48.7	5.8	44.7	0.6	18.8	8088
Birch	49.8	6.5	43.4	0.3	20.12	8656
Elm, rock	50.4	6.6	42.3	0.7	20.49	8815
Maple, hard (black)	50.64	6.02	41.74	1.35	19.96	8587
Maple, hard (sugar)	50.64	6.02	41.74	1.35	19.96	8587
Oak, red	49.5	6.62	43.7	0.2	20.2	8690
Oak, white	50.4	6.59	42.7	0.2	20.5	8819
Pine, Southern, longleaf	52.6	7.02	40.1	1.3	22.3	9594
Douglas Fir	48.73	6.87	43.9	0.5	19.81	8522

X1.2.1.1 *single burn rate appliance, n*—a wood heater with combustion air control(s) that is not adjustable by the heater user and that meets the requirements of **X1.4.2**.

X1.3 Summary of the Test Method

X1.3.1 The procedures in this annex allow the determination of performance for single burn rate appliances by addressing the differences in operation between heaters with adjustable combustion air controls and those with non-adjustable combustion air control(s). The difference in the procedure for testing single burn rate appliances involves how the heater is operated, the number of test runs required and the determination of average emissions.

X1.4 Procedure

X1.4.1 Other than the requirements for testing at low, medium and maximum burn rates in **9.5.1** in the test method, all other test method test procedure requirements must be met.

X1.4.2 Conduct at least two test runs following the manufacturer's written instructions for operation of the heater. The heater shall be considered to have a single burn rate if the burn rate for any individual test run is within 10 % of the average burn rate for all test runs.

X1.4.3 For heaters with automatic controls, the controls may be allowed to function in a manner consistent with the owner's manual and with normal operation in a home as long as the requirements of **X1.4.2** are met.

X1.5 Data Analysis and Calculations

X1.5.1 Nomenclature:

$$PM_{RA} = (PM_{R1} + PM_{R2} + \dots PM_{Rn})/n \quad (X1.1)$$

where:

PM_{RA} = the average emission rate, g/h (lb/h),
 PM_{R1} = the emission rate for test run 1, g/h (lb/h),

PM_{R2} = the emission rate for test run 2, g/h (lb/h),
 PM_{Rn} = the emission rate for each additional valid test run, g/h (lb/h), and
 n = number of valid test runs.

$$PM_{FA} = (PM_{F1} + PM_{F2} + \dots PM_{Fn})/n \quad (X1.2)$$

where:

PM_{FA} = the average emission factor, g/kg (lb/ton),
 PM_{F1} = the emission factor for test run 1, g/kg (lb/ton),
 PM_{F2} = the emission factor for test run 2, g/kg (lb/ton),
 PM_{Fn} = the emission factor for each additional valid test run, g/kg (lb/ton), and
 n = number of valid test runs.

$$PM_{AH} = (PM_{1H} + PM_{2H} + \dots PM_{nH})/n \quad (X1.3)$$

where heat output is determined in accordance with **Annex A2**:

PM_{AH} = arithmetic average emissions per heat output unit for all test runs, g/MJ (lb/MMBtu),
 PM_{1H} = average emissions per heat output unit for test run 1, g/MJ (lb/MMBtu),
 PM_{2H} = average emissions per heat output unit for test run 2, g/MJ (lb/MMBtu), and
 PM_{nH} = average emissions per heat output unit for each additional test run n, g/MJ (lb/MMBtu).

$$\eta_A = (\eta_1 + \eta_2 + \dots \eta_n)/n \quad (X1.4)$$

where:

η_A = arithmetic average overall efficiency for all test runs, %,
 η_1 = average overall efficiency for test run 1 as determined in accordance with **Annex A2**, %,
 η_2 = average overall efficiency for test run 2 as determined in accordance with **Annex A2**, %, and
 η_n = average overall efficiency for each additional test run n as determined in accordance with **Annex A2**, %.

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