Designation: E2817 – 11

Standard Test Method for Test Fueling Masonry Heaters[1]

1. Scope

1.1 This test method covers the fueling and operating protocol for determining particulate matter emissions from solid fuel biomass (cordwood or other densified, binder free biomass fuels) fires in masonry heaters. It may also be used to test other similar appliances (see 3.2.20).

1.2 This test method is applicable to the operation and fueling of masonry heaters during particulate emissions measurement test periods. The prescribed methods and procedures of these protocols are performed on masonry heaters installed and operated in accordance with the builder or manufacturer's specifications.

1.3 In conjunction with Test Method E2515, this test method provides a protocol for laboratory emissions testing of masonry heaters that is intended to simulate actual use in residential homes and other consumer applications. Since such actual use involves almost solely cordwood fueling, Annex A1, Cordwood Fuel, provides as close a simulation as is currently possible of consumer use, and is recommended for predicting actual consumer emissions performance. For regulatory and other potential uses in comparing relative emissions of various masonry heater products and designs, Annex A2, Cribwood Fueling, and Annex A3, Cribwood Fuel, Top-Down Burn, provide optional additional fueling protocols that substitute dimensional lumber cribs for the cordwood fuel. Data that establish the relationships between the emissions results generated by Annex A2 and Annex A3 and the emissions results generated by Annex A1 are not currently available.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.5 *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.*

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.54 on Solid Fuel Burning Appliances.

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2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E1602 Guide for Construction of Solid Fuel Burning Masonry Heaters

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

2.2 *Other Standards:*

EN 15250 Slow Heat Release Appliances Fired By Solid Fuel-Requirements And Test Methods

EN 15544 One Off Kachelgrundfen/Putzgrundfen (Tiled/Mortared Stoves): Calculation Method

NIST Monograph 175 Standard Limits of Error[3]

US EPA Title 40 Code of Federal Regulations[4]

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 *ashpit loss, n*— the incomplete burned residue (charcoal) left with the ash after a test run is completed.

3.2.2 *burn rate, n*—the average rate at which test-fuel is consumed in a masonry heater during a test run. The burn rate excludes the inorganic salts and minerals (that is, "ash") and incompletely burned residues (charcoal) remaining at the end of a test run; measured in mass of dry wood burned per hour (kg/hour, lb/hour).

3.2.3 *calibration error, n*—the difference between the gas concentration displayed by a gas analyzer and the known concentration of the calibration gas when the calibration gas is introduced directly to the analyzer.

3.2.4 *calibration (span) drift, n*—The difference between the expected instrument's response and the actual instrument's response when a calibration (span) gas is introduced to the

[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] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

[4] Available from United States Environmental Protection Agency (EPA), Ariel Rios Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20004, http://www.epa.gov.

analyzer after a stated period of time has elapsed during which no maintenance, repair or adjustment has taken place:

$$\text{calibration (span) drift} = \left(\frac{(\text{actual response} - \text{expected response})}{\text{expected response}}\right) \times 100$$

3.2.5 *calibration (span) gas, n*—a known concentration of carbon dioxide (CO_2), carbon monoxide (CO), or oxygen (O_2) in nitrogen (N_2), or a combination thereof.

3.2.6 *combustion period emissions rate (ER_{CP}), n*—the particulate emissions rate during the masonry heater combustion period only (cf. *heating cycle emissions rate*).

3.2.7 *Douglas fir, n*—for crib fueling protocols; untreated, standard, or better grade Douglas fir lumber with agency grade stamp: D. Fir or Douglas Fir.

3.2.8 *flue-gas temperature, n*—the temperature measured at the primary flue-gas sampling and temperature measurement location: Pre-Test flue-gas temperature is measured at the Primary Flue-Gas Sampling and Temperature Measurement Location within 15 minutes before a test is initiated and at least 1 hour after the masonry heater was closed in accordance with 9.5.2.

3.2.9 *firebox, n*—the chamber within the masonry heater where the fuel is placed and combusted.

3.2.10 *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 (in non orthogonal fireboxes the fuel load will be placed according to the builder or manufacturer's instructions or at the best judgment of the testing lab).

3.2.11 *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 (in non orthogonal fireboxes the fuel load will be placed according to the builder or manufacturer's instructions or at the best judgment of the testing lab).

3.2.12 *firing interval (Θ_{FI}), n*—the period of time during which the stored heat energy is released prior to the next firing, as specified by the builder or manufacturer.

3.2.13 *fuel crib, n*—the fuel load placed in the firebox prior to the test start. The fuel crib includes all of the kindling pieces, fuel pieces and spacers needed to assemble a fuel crib. Specific fuel crib configurations are described in Annex A2, Cribwood Fueling, or Annex A3, Cribwood Fuel, Top-Down Burn.

3.2.14 *fuel piece, n*—(*1*) *cordwood fuel*: triangularly split solid wood fuel: each piece shall be able to pass through a 152-mm (6-in.) hole while not passing through a 76-mm (3-in.) hole. Other cordwood cross sections shall be allowed if specified in the builder or manufacturer's instructions. (*2*) *crib fuel*: "2 × 2", "2 × 4" or "4 × 4" wood pieces used to construct fuel cribs: "2 × 2", "2 × 4" and "4 × 4" referring to the nominal width and depth dimensions for commonly available dimensional lumber. The actual dimensions are 38 mm × 38 mm (1½ in. × 1½ in.), 38 mm × 89 mm (1½ in. × 3½ in.) and 89 mm × 89 mm (3½ in. × 3½ in.).

3.2.15 *fuel weight, total, n*—(*1*) *cordwood*: the total weight of the kindling and fuel pieces used in a test run (the test load can be added as multiple fuel loadings if the builder or manufacturer indicates this in the operating instructions; no such individual fuel loading shall be less than 20 % of the total fuel weight). (*2*) *crib fuel*: the total weight of the kindling and fuel pieces and spacers.

3.2.16 *heating cycle emissions rate (ER_{HC}), n*—the effective particulate emissions over the heating cycle of the masonry heater. It is calculated based on the builder or manufacturer's specified period of time between firings in which the heat stored in the masonry heater radiates useful heat to the heated space (cf. *combustion period emissions rate*).

3.2.17 *internal assembly, n*—the core construction and firebox design factors that may affect combustion function or particulate emissions factor of a masonry heater.

3.2.18 *grate, n*—for the purposes of masonry heater testing and operation, any grate included with the masonry heater or specified by the masonry heater builder or manufacturer for the purpose of supplying combustion air, elevating the fuel load above the hearth, preventing fuel pieces from falling outside the intended burning area, or all of the above. The volume below a fuel-elevating grate shall not be considered part of the usable firebox volume.

3.2.19 *kindling brand, n*—the fuel comprised of fuel strips separated by air spaces and placed above or contiguous to crumpled newspaper to initiate combustion in the tested masonry heater (see Annex A2, Cribwood Fueling, or Annex A3, Cribwood Fuel, Top-Down Burn).

3.2.20 *masonry heater, n*—solid-fuel biomass burning appliance or unit as described in Guide E1602. This method may also be used in testing other appliances conforming to EN 15250 or EN 15544, or both, but not necessarily conforming to the Guide E1602 masonry heater definition.

3.2.21 *maximum flue-gas oxygen depression, n*—the difference between the baseline air supply oxygen concentration (that is, 20.9 %) and the lowest oxygen concentration measured and recorded during the test run or, alternatively, the difference between the base line air supply oxygen concentration (20.9 %) and the lowest oxygen measured and recorded during the test run determined by subtracting the maximum flue gas carbon dioxide (CO_2) and carbon monoxide (CO) values from 20.9 %:

$$\text{maximum } O_2 \text{ depression} = 20.9\,\% - \left[\%\,CO_2 + \left(\%\,\frac{CO}{2}\right)\right]$$

3.2.22 *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.

3.2.23 *primary flue-gas sampling and temperature measurement location, n*—area within the center 33 % of the cross-sectional area of the flue-gas exhaust duct at the point 30 cm (12 in.) downstream from the beginning of the flue collar or chimney system anchor plate or other connector used to connect the chimney to the masonry heater.

3.2.24 *response time, n*—the amount of time required for a gas measurement system to respond and display a 95 % step change in a gas concentration.

3.2.25 *sampling system bias, n*—the difference between the gas concentrations displayed by an analyzer when a gas of known concentration is introduced at the inlet of the sampling probe and the gas concentration displayed when the same gas is introduced directly to the analyzer.

3.2.26 *spacers, n*—wood pieces used to hold individual fuel pieces together when constructing fuel cribs. Their function is to provide reproducible fuel crib geometry and air spaces between fuel pieces, as well as to hold the fuel cribs together (with nails).

3.2.27 *span (or span value), n*—the upper limit of a gas analyzer's measurement range. (Typically 25 % for CO_2 and O_2, and 5 % or 10 % for CO.)

3.2.28 *test run, n*—the time from the start of a test at ignition until the time flue-gas oxygen concentration has recovered to at least 95 % of the ambient oxygen concentration. A valid test must consume at least 90 % of the test fuel weight (see 9.5.8.2).

3.2.29 *test facility, n*—the area in which the masonry heater is installed, operated, and sampled for emissions; may include commercial and residential structures.

3.2.30 *test-fuel loading factor, n*—the ratio between test-fuel crib volume, including kindling pieces and inter-fuel-piece spacing, and the usable firebox volume. For these protocols, the test-fuel loading factor for masonry heaters is 0.30 (that is, 30 %) unless otherwise specified.

3.2.31 *test series, n*—a group of test runs at a lab on the same masonry heater.

3.2.32 *total sampling time (Θ), n*—the time that elapses between the start of the test as described in 9.5.3 and the end of the test as described in 9.5.7 (in minutes).

3.2.33 *usable firebox height, n*—the height within the firebox at or below which fuel is placed. The usable firebox height is to be specified by the builder or manufacturer. In the absence of a builder or manufacturer specification, the usable firebox height is the height of the top of the loading door.

3.2.34 *usable firebox volume (F_v), n*—the volumetric space within the firebox of a masonry heater into which fuel is intended to be placed.

3.2.35 *zero drift, n*—The difference between the expected instruments response and the actual instruments response when a zero gas is introduced to the analyzer after a stated period of time has elapsed during which no maintenance repair or adjustment has taken place:

$$\text{zero drift} = \left(\frac{(\text{actual response} - \text{expected response})}{\text{span (span value)}}\right) \times 100$$

3.2.36 *zero gas, n*—a gas with no detectable (measurable) amounts of CO_2, CO, or O_2 (usually N_2), or a combination thereof.

4. Summary of Test Method

4.1 This test method is to be used in conjunction with Test Method E2515. The test masonry heater is constructed, fueled, and fired according to the builder or manufacturer's installation and operating instructions. In the absence of such written instructions, this test method provides defaults for the testing laboratory or other users to determine needed testing values.

4.2 The builder or manufacturer of the masonry heater being evaluated shall provide the following, as furnished to consumers or other end users:

4.2.1 Minimum and maximum designed heating capacity in kilowatts (BTU/hr),

4.2.2 Firing interval (hours),

4.2.3 Minimum and Maximum fuel load in kilograms (pounds),

4.2.4 Usable firebox dimensions in centimetres (inches) and volume in cubic centimetres (cubic inches),

4.2.5 Fuel piece length in centimetres (inches), and

4.2.6 A copy of the operating manual as furnished to consumers or other end users.

5. Significance and Use

5.1 This test method is used for determining emission factors and emission rates for cordwood or other densified, binder free biomass fuel burning masonry 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 masonry heaters, but must be used with caution as use patterns must be factored into any prediction of atmospheric particulate matter impacts from masonry heaters based on results from this method.

5.2 The reporting units are grams of particulate per kilogram of dry fuel (emissions factor), grams of particulate per hour of heating cycle (heating cycle emissions rate, based on the builder or manufacturer's specified firing interval), and grams of particulate per hour of test run (combustion period emissions rate, based on the tested combustion period).

5.3 **Warning—**Use of masonry heater emissions rate reporting numbers (grams per hour) for comparative purposes with other solid fuel burning appliances will require careful study of each of the appliance's comparative operating characteristics in the given application. Intermittently fired appliances such as masonry heaters and continuously fired appliances such as wood and pellet stoves are not accurately compared by their respective emissions rates.

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 *Masonry 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. This must meet the calibration requirements specified in 8.3.

7.2 *Test Facility Temperature Monitor*—A thermocouple located centrally in a vertically oriented 150 mm (6 in.) long, 50-mm (2-in) diameter pipe shield that is open at both ends. This must meet the calibration requirements specified in 8.3.

7.3 *Test Fuel Scale*—A scale capable of weighing test fuel pieces or test cribs to within 0.005 kg (0.01 lb). This must meet the calibration requirements specified in 8.2.

7.4 *Wood Moisture Meter*—A calibrated electrical resistance meter capable of measuring test fuel moisture to within 1 % moisture content. This must meet the calibration requirements specified in 8.1.

7.5 *Anemometer*—A device capable of detecting air velocities less then 0.10 m/sec (20 ft/min) and used for measuring air velocities in the test facility near the test appliance.

7.6 *Barometer*—A mercury, aneroid, or other barometer capable of measuring atmospheric pressure with an accuracy of ±2.5 mm Hg (±0.01 in. Hg). This must the meet calibration requirements specified in 8.6.

7.7 *Draft Gauge*—An electro-manometer or inclined liquid manometer for the determination of flue/chimney draft (that is, static pressure) readable to within 1.0 Pa (0.02 in.).

7.8 *Flue-Gas Sample Conditioning System*—The flue gas conditioning system consists of a high density filter to remove particulate matter and a condenser capable of lowering the dew point of the gas to less than 5°C (40°F). A desiccant may be used to dry the sample gas. The temperature sensor measuring the temperature of the gas exiting the condenser in the gas conditioning system shall be inserted directly into the gas stream. If the high density filter is heated to help prevent clogging, the sample gas exit temperature shall be ≤120°C (≤248°F). The temperature shall be measured with the temperature sensing device inserted in the gas stream within 1-in. downstream of the filter support (frit). The temperature sensing devices must be capable of measuring the flue gas sample stream temperature(s) with an accuracy of 2.2°C (4°F). This must meet calibration requirements specified in 8.3. The gas conditioning system consists of the following:

7.8.1 *Probe*—A stainless steel probe (304 or better) with a 6.3-mm (0.25-in.) inside diameter (ID) and at least long enough to reach the far side of the chimney/flue at the flue gas sampling location.

7.8.2 *Filters*—In line high density fiberglass filters to remove solids and condensable materials from the sample gas stream. Disposable filter cartridges may be used.

7.8.3 *Condenser/Dryer*—Any system capable of condensing the water vapor and organics in the gas sample.

7.8.4 *Vacuum Gauge*—A vacuum gauge with a range of 0 to 760 mm (0 to 30 in.) to measure the vacuum on the suction side of the pump during leak checks and operation.

7.8.5 *Flow Meter*—A rotameter with a flow control valve that has a range that contains the flow rate required by the gas analyzer. If two or more analyzer's are used, each analyzer shall have a flow meter controlling the gas sample flow to it. The rotameters controlling the sample flow rate to each analyzer shall be installed immediately upstream of the analyzers. A flow meter is also required for determining flows during leak checks if the sample flow is rerouted away from the gas analyzers during leak checks.

7.8.6 *Pump*—An inert (that is, Teflon or stainless steel heads) sampling pump capable of delivering more that the total amount of sample required in the manufacturer's instructions for the individual instruments.

7.9 *Gas Analyzer*—A gas analyzer capable of measuring oxygen (O_2) in the range of 0.0 % to 25.0 % or, alternatively, carbon dioxide (CO_2) in the range of 0.0 % to 25.0 % and carbon monoxide (CO) in the range of 0.00 % to 5.00 % or 0.00 % to 10.00 %. All flue-gas analyzers shall meet the measurement system performance specifications in 8.8.

8. Calibration and Standardization

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

8.2 *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 run, audit the scale by weighing at least one calibration weight (ASTM Class F) that corresponds to between 20 % and 80 % of the expected test fuel piece or test fuel crib 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 piece or test fuel crib weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

8.3 *Temperature Sensors*—Temperature measuring equipment shall be calibrated before initial use and at least semiannually thereafter. Calibrations shall be in compliance with NIST Monograph 175.

8.4 *Anemometer*—Calibrate the anemometer in accordance with the manufacturer's instructions before initial use and semiannually thereafter.

8.5 *Barometer*—Calibrate the barometer against a mercury barometer before initial use and at least semiannually thereafter.

8.6 *Draft Gauge*—Calibrate the draft gauge in accordance with the manufacturer's instructions before initial use and at least semiannually thereafter.

NOTE 1—An inclined liquid manometer does not require calibration but must be checked for level and zero before each test run.

8.7 *Gas Analyzer Calibration*—The O_2 analyzers or CO_2 and CO analyzers, or both, shall be calibrated in accordance with the manufacturer's instructions and the procedures specified in 9.3.4.

8.7.1 *Sampling System Bias*—The bias shall be ≤3 % of the span value for the high-range calibration gas used.

8.7.2 *Resolution*—The resolution of the output from each gas analyzer shall be at least 0.01 % of the span value.

8.7.3 *Analytical Interference*—The interference of CO measurements caused by the presence of CO_2 in the flue-gases shall be determined by the sampling of high-range CO_2 calibration gas through the CO analyzer system. A calibration gas in the range of 10 % to 12 % CO_2 and 0.00 % CO by volume shall not cause the CO analyzer to indicate a measurement of more than 0.20 % CO.

8.7.4 *Carbon Dioxide (CO_2) Gas Analyzer Accuracy Limitation*—If the average test run flue-gas CO_2 plus CO is not greater than 2.0 %, the CO_2 analyzer shall have a resolution of at least 100 parts per million (0.01 %).

8.8 *Sampling Supplies and Reagents:*

8.8.1 *Calibration Gases*—Calibration gases for each flue-gas constituent to be measured shall have concentrations in each of the nominal ranges indicated in Table 1. Mixtures or combinations of the calibration gases may be used in place of separate cylinders for each calibration constituent.

NOTE 2—All calibration gas mixtures shall be certified by the gas supplier or laboratory using the methods referenced in US EPA Title 40, Code of Federal Regulations, Part 60, Appendix A: Methods 3 and 10.

8.9 *Sample Flow Rates and System Response Times*—The flue-gas sampling (that is, extraction) rate for gas analyses shall be set in accordance with the instrument manufacturer's recommended range within 30 minutes before sampling begins or the system response time is measured. The determination of the response time for the gas sampling system shall be conducted before initial use and semiannually thereafter or immediately after a flue gas conditioning system component is changed.

8.9.1 *Response Time Measurement*—The response time for all flue-gas sampling systems shall be determined by a measurement of a step change in analyte gas concentration. First, supply a low-range analyte calibration gas (see Table 1) into the probe inlet until the gas analyzer's response has stabilized. After the gas analyzer's response has stabilized, switch the probe to the high-range calibration gas and immediately start timing the system response time. Response time shall be measured starting at the time the low-range analyte calibration gas is switched to the high-range calibration gas and ending at the time the respective analyte analyzer reading is 95 % of the difference in the calibration gas concentrations utilized. Or alternatively, insert the probe of a complete leak checked flue-gas sampling system into a flue connected to a solid fuel burning appliance with a fire burning in it. At the flue-gas sampling port used during testing allow the flue gas sampling system to operate until a stable reading is obtained on the gas analyzer(s). Then remove the probe from the chimney, simultaneously starting a stop watch. Note and record the amount of time to the initial gas analyzer(s) response and the time it takes to reach a 95 % change in the gas analyzers response. Continue to measure the response for each analyzer until the output is 0.00 % for CO_2 and CO analyzers or 20.9 % for O_2 analyzers.

NOTE 3—For the most accurate response time measurement use the above procedures with a large hot coal bed with the masonry heater's air controls set on high.

TABLE 1 Nominal Calibration Gas Concentrations (Percent of Span Value)

Range	Oxygen (O_2)	Carbon Dioxide (CO_2)	Carbon Monoxide (CO)
High	80 % – 90 %	80 % – 90 %	80 % – 90 %
Mid	45 % – 55 %	45 % – 55 %	45 % – 55 %
Low	20 % – 30 %	20 % – 30 %	20 % – 30 %

9. Procedure

9.1 *Preconditioning*—The test masonry heater may be fired prior to the test period for the purposes both of curing and drying the masonry materials, and to facilitate a warm start for a test run. All preconditioning shall be performed in accordance with builder or manufacturer's instructions. The final firing prior to initial test will be performed according to the builder or manufacturer's instructions for a normal firing (including shut down procedures) and will take place no later than one firing interval prior to the test start.

9.1.1 *Firebox Residue*—The firebox shall be cleaned prior to the initial test run in a test series. The residue from the pre-test firing may be weighed and returned to the firebox prior to the test firing. (This simulates consumer operation, in which residue from one firing would be left in the firebox and available for the next firing).

9.1.2 *Masonry Heaters with Optional Equipment*—If the test masonry heater includes standard (or offers optional) components that might affect particulate emission performance (including but not limited to catalytic combustors, water heating coils, heat exchange blowers, air supply options, dampers, different chimney types, and mechanical draft inducers), separate emissions tests may be required for each of the various positions or conditions that are allowed. In the event that a masonry heater is equipped with user controlled adjustable equipment, adjustments shall be made according to the instructions provided. If the operation of adjustable features is not specified in a builder or manufacturer's written instruction manual, all optional features, including adjustment of pump or blower speeds, shall be operated at a maximum rate (most disadvantageous to combustion) throughout the test.

9.1.3 *Bypass Damper Operation*—Auxiliary equipment, such as bypass dampers may be adjusted only once during the test period and the adjustment shall be in accordance with the builder or manufacturer's written instructions. Record and report all adjustments made to auxiliary masonry heater equipment during the test period.

9.1.4 *Flue-Gas Stratification Check*—During the masonry heater aging and curing period specified in 9.1, use the gas analyzer(s) and sampling system specified in 7.8 to determine whether flue gases become stratified in the flue/chimney cross-section at the primary flue-gas sampling and temperature measurement location specified in 9.2.3.

9.1.4.1 *Stratification of Flue-Gas CO and CO_2 Concentrations*—The stratification of flue-gas CO and CO_2 concentrations shall be determined by first sampling at the flue-gas sampling and temperature measurement location at the center of the flue/chimney for at least 30 seconds after gas analyzer readings have stabilized, and then sampling within 25 mm (1 in.) of the flue/chimney wall for the same period.

This procedure is to be repeated on at least two points in the horizontal plane of the flue/chimney cross-section. Flue-gas concentration differences of more than 15 % of the highest concentration measured at any of the other three cross-section sample points shall be considered stratified.

9.1.4.2 *Stratification Remedy*—The presence of a stratified flue-gas flow regime at the Primary Flue-Gas Sampling Location shall be remedied by changing the location of flue-gas sampling and temperature measurement probes to ones that equally and simultaneously sample the flue-gases and temperatures in the center of at least four separate and equal areas of the flue/chimney cross-section.

9.2 *Installation of the Masonry Heater into the Test Facility:*

9.2.1 *Construction*—The masonry heater being tested must be constructed (as for site-built units) or installed (as for manufactured units) in accordance with the designer or manufacturer's written instructions.

9.2.1.1 *Chimney*—For test purposes the chimney shall have a total vertical height above the hearth of not less than 4.6 m (15 ft) or more than 5.5 m (18 ft), as in accordance with Test Method E2515. For masonry heaters specifying higher drafts than can be attained with this chimney configuration, a draft may be induced, measured 30.5 cm (12 in.) above the chimney connection point (cf. EN 15250). Unless otherwise stipulated in the written installation instructions, the chimney exit to the dilution tunnel hood must be freely communicating with the masonry heater combustion makeup-air source.

NOTE 4—The chimney that is used for testing should be documented in the test data and test report, including induced draft, if any.

9.2.2 *Flue Outlet*—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.

NOTE 5—If the dilution tunnel is used to induce a draft, the requirements in Test Method E2515, Section 9.2.3, do not need to be met. If the dilution tunnel is used to induce a draft in the masonry heater's chimney/flue, document the distance between the top of the chimney and the top of the dilution tunnel hood and the flow rate through the tunnel the induced draft should be set when the unit is cold, prior to any firing.

9.2.3 *Primary Flue-Gas Sampling and Temperature Measurement Location*—Flue gas sampling shall occur within the chimney attached to the masonry heater 228.5 cm ± 30.5 cm (90 in. ± 12 in.) above the top of the surface upon which any builder or manufacturer supplied components are placed, or 30.5 cm (12 in.) from the lowest point of the chimney in contact with the masonry heater, whichever is least. The flue-gas temperature probe shall also be positioned within the Primary Flue-Gas Sampling Location but shall not interfere in any way with any other sample probe sensors or inlets.

9.2.4 *Room Air Velocity Measurement*—Measure using the anemometer described in 7.5. Once the masonry heater is installed in the test chamber as in accordance with 9.2 and before lighting the first fire in the heater measure the air velocities within 0.5 meters (19.7 inches) of the masonry heater walls and combustion air intake(s). The room air velocity shall be less than 0.25 m/sec (50 ft/min).

9.3 *Additional Preparations:*

9.3.1 *Masonry Heater Description*—Prepare a written description of the masonry heater being tested including any catalyst or add-on emissions control devices, or both. The masonry heater description shall include photographs showing all externally observable features, or drawings, or both, showing all internal and external dimensions needed for fabrication or construction, or both. The photographs or drawings, or both, must be verified and certified as representing the tested masonry heater by the testing laboratory.

9.3.2 *Test Facility Ambient Temperature Probe*—Locate the test-facility ambient temperature probe on the horizontal plane that includes the primary air intake opening for the masonry heater. Locate the temperature monitor probe at a distance of 1 to 2 m (3 to 6 ft) from the front of the masonry heater and in a 90° sector defined by lines drawn at ±45° from a perpendicular line to centerline of the masonry heater face.

9.3.3 *Leak Check*—A leak check of all flue-gas sampling systems shall be performed before each test run is started. Leak checks shall be performed as follows.

9.3.3.1 *Leak-Check Procedure*—Seal the probe inlet for each sampling system or train. Use the sample pump controls to create a vacuum greater than either twice the maximum vacuum encountered during test period sampling, or 125 mm (5 in.) of mercury, whichever is greater. Record the resulting sample flow rate indicated by the instrument flow meter when the required vacuum is achieved, corrected for system pressure, if applicable.

9.3.3.2 *Leak Check Acceptance Criteria*—Unless the leakage rate under the required vacuum is less than 2 % of the average sample flow rate, test results shall be invalid.

9.3.4 *Gas Analyzer Calibration*—Calibrate the O_2 or CO_2 and CO analyzers, or both, as follows before the first run in a test series.

9.3.4.1 Following the manufacturer's instructions, allow the analyzer to operate and stabilize prior to calibration.

9.3.4.2 Introduce zero gas to the analyzer at the same flow rate that is to be used during testing. Allow the analyzer's output to stabilize. Then as necessary, adjust the analyzer's output so that it reads zero. Note and record the analyzer's pre and post adjustment output and all other pertinent information, for example, potentiometer settings, B.P., temperature, and DAS valve.

9.3.4.3 Introduce the mid range calibration gas to the analyzer at the same flow rate that is to be used during testing. Allow the analyzer's output to stabilize. Then as necessary adjust the analyzer's output so that the output matches the calibration gas. Note and record the analyzer's pre and post adjustment output and all other pertinent information, for example, potentiometer settings, B.P., temperature, and DAS Value.

9.3.4.4 Then, in turn introduce the high and low range calibration gases to the analyzer at the same flow that will be used during testing. Allow the analyzer's output to stabilize. Note and record the analyzer's output and all other pertinent information.

9.3.4.5 Calculate and plot a linear least squares calibration curve for each analyzer.

(1) Using the least square calibration curve calculate the actual response for each of the four calibration gases. The analyzer's actual response for each calculation gas must be within ±2.0 % of the calibration gas concentration for the calibration to be valid:

$$\left[\text{Zero gas} \;=\; \left(\frac{(\text{Actual Response} - 0.000)}{\text{Expected Response}}\right) \times 100\,,\; \text{Calibration (Span) Gases} = \left(\frac{(\text{Actual Response} - \text{Expected Response})}{\text{Expected Response}}\right) \times 100\right]$$

9.3.4.6 Once the CO analyzer is properly calibrated, introduce a calibration gas containing 10 % to 12 % CO_2 to the CO analyzer at the same flow to be used during testing. Allow the CO analyzer's output to stabilize. The CO analyzer's output shall not be more than 0.20 % CO.

9.4 *Fuel:*

9.4.1 *Fuel Properties and Firebox Loading*—Fuel and firebox loading method shall conform to either Annex A1, Cordwood Fuel; Annex A2, Cribwood Fueling; or Annex A3, Cribwood Fuel, Top-Down Burn.

9.5 *Operation:*

9.5.1 *Masonry Heater Cooling Period*—No fuel shall be burned in the masonry heater to be tested and no other means for heating the masonry heater shall be used within one firing interval of the start of a test run.

9.5.2 *Pre-Test-Firing Procedures:*

9.5.2.1 *Room-Air Velocity*—Using an anemometer, measure and record the room-air velocity within 0.5 m (19.7 in.) of the test masonry heater air supply duct intake or fuel loading door, within one hour before the start of each test run. Air velocity at the specified locations shall be less than 60 m/min (200 ft/min). No external means shall be used to affect air velocities within 0.5 m (2 ft) of the test masonry heater during a test period.

9.5.2.2 *Barometric Pressure*—Measure and record the barometric pressure within one hour before the start of a test run.

9.5.2.3 *Flue-Gas Temperature Determination*—At least one hour before initiating a test run (that is, ignition of a fire in the masonry heater), close all air supply controls and the masonry heater fuel loading door(s). After one hour of masonry heater air-supply and open-face-area closure and within 5 minutes before opening the door(s) or any other means for closing the open face area of the masonry heater to initiate test-fire ignition, measure and record the pre-test flue-gas temperature at the flue-gas sampling and temperature measurement location.

9.5.2.4 *Pre-Test Gas Analyzer Zero Check*—within two hours of the start of a test run introduce a zero gas to each analyzer at the same flow to be used during testing. Allow the analyzer's output to stabilize. Note and record the analyzer's output. Using the least squares calibration curve, calculate the analyzer's actual output. Each analyzer's output must be within 5.0 % of the expected output. If the output is greater than 5.0 %, the analyzer must be recalibrated:

$$\left[\Delta\% = \left(\frac{(\text{Actual Response} - 0.000)}{\text{Span Value}}\right) \times 100\right]$$

9.5.2.5 *Pre-Test Gas Analyzer Span Check*—within two hours of the start of a test run introduce a mid range calibration (span) gas to each analyzer at the same flow rate to be used during testing. Allow the analyzer's output to stabilize. Note and record the analyzer's output. Using the least squares calibration curve, calculate the analyzer's actual output. Each analyzer's actual output must be within 5.0 % of the expected output. If the output is greater than 5.0 %, the analyzer must be recalibrated:

$$\left[\Delta\% = \left(\frac{(\text{Actual Response} - \text{Expected Response})}{\text{Expected Response}}\right) \times 100\right]$$

9.5.3 *Test Run Start*— when all of the requirements for starting the emissions test are met in accordance with Test Method E2515, simultaneously start the sampling equipment and ignite the newspaper balls. A propane gas torch has been found to be a good device for obtaining rapid and even ignition of the newspaper. Quickly work your way from one side to the other to ensure even ignition. All newspaper must be ignited within 30 seconds from starting the sampling equipment.

9.5.4 *Data Recording Requirements*—Once test sampling and temperature measurements have begun at the start of a test in accordance with 9.5.3, all test sampling, parameter measurement, and data recording requirements shall be conducted at least every 5 minutes and continue without interruption until the test is terminated in accordance with 9.5. Test-time sampling and temperature measurement parameters shall include:

9.5.4.1 Test facility temperature;

9.5.4.2 O_2 or $CO_2 + CO$ concentrations, or both;.

9.5.4.3 Flue-gas temperature; and

9.5.4.4 All flue-gas sample-train/sample-system sampling rates and gas conditioning equipment temperatures.

9.5.4.5 Static pressure at the primary sampling and temperature measurement location.

9.5.5 *Test Facility Ambient Temperatures*—Test facility ambient temperatures shall be maintained between 13 and 32ºC (55 and 90ºF) during all test periods.

9.5.6 *Test-Fuel Charge Adjustments*—Test-fuel charges may be adjusted (that is, repositioned) once during the burning of each test-fuel charge after flue gas O_2 recovery = 65 %. The time used to make this adjustment shall not exceed 30 seconds.

9.5.7 *Test Completion*—A test run is completed and all sampling and test-period temperature measurements are stopped at the end of the first five-minute interval after which the flue-gas oxygen concentration has recovered (that is, increased) to 95 % of the maximum flue-gas oxygen depression value which resulted from the combustion of the test-fuel charge.

9.5.8 *Post-Test Procedures:*

9.5.8.1 *Room-Air Velocities*—Using a low-velocity-range anemometer, within 10 minutes after test completion, measure and record the room-air velocity within 0.5 m (19.2 in.) of the test masonry heater.

9.5.8.2 *Fuel Weight at Test Completion*—Within 5 minutes after test completion, as defined in 9.5.7, the remaining coals or unburned fuel or ash residues, or any combination thereof, shall be carefully removed from the firebox and weighed to the nearest 0.05 kg (0.1 lb). Once weighed, the residue can be placed in the firebox again, and the heater shut down as per builder or manufacturer instructions. This simulates actual usage, during which residues would be used as fuel in the following burn cycle. A test-burn shall be invalid if less than 90 % of the weight of the total test-fuel charge has been burned.

9.5.8.3 *Barometric Pressure at Test Completion*—Measure and record the barometric pressure within 10 minutes after test period completion.

9.5.8.4 *Post Test Gas Analyzer Zero Check*—Within one hour of the end of the test as defined in 9.5.7 introduce a zero gas to each analyzer at the same flow used during the test. Allow the analyzer's output to stabilize. Not and record the analyzer's output. Using the least squares calibration curve, calculate the analyzer's actual output. Each analyzer's actual output must be within ±5.0 % of the expected output. If the output is greater than ±5.0 %, the test run is invalid and the analyzer must be recalibrated:

$$\left\{\Delta\% = \left[\frac{(\text{Actual Response} - 0.000)}{\text{Span Value}}\right] \times 100\right\}$$

9.5.8.5 *Post Test Gas Analyzer Span Check*—Within one hour of the end of the test as defined in 9.5.7 introduce a mid range calibration gas to each analyzer at the same flow rate to be used during testing. Allow the analyzer's output to stabilize. Note and record the analyzer's output. Using the least squares calibration curve, calculate the analyzer's actual output. Each analyzer's actual output must be within ±5.0 % of the expected output. If the output is great than 5.0 %, the test run is invalid and the analyzer must be recalibrated:

$$\left\{\Delta\% = \left[\frac{(\text{Actual Response} - \text{Expected Response})}{\text{Expected Response}}\right] \times 100\right\}$$

9.5.8.6 *Other Quality Assurance Checks:*

(1) Thermocouple Readouts—Using a thermocouple simulator generate a zero and span signal. Allow each reading to stabilize. Note and record output.

(2) Static Pressure (Pg)—Check the level and zero reading.

10. Data Analysis and Calculations

10.1 *Data Sheet*—After test completion, data sheets shall be reviewed for completeness and proper equipment operation. The data sheets, log books, and records maintained by laboratory staff shall be reviewed to ensure completeness and readability. Test run data sheets shall be used to calculate masonry heater operational parameters and test run results.

10.2 *Calculations*—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.

10.3 *Nomenclature:*

$$M_{FTAdb} = M_{FCdb} + M_{CR} \quad (1)$$

where:

M_{FCdb} = weight of fuel crib (cordwood; fuel load), dry basis, kg (lb);
M_{CR} = weight of charcoal returned to firebox after pretest warm up or previous test run, kg (lb); and
M_{FTAdb} = total weight of fuel added, dry basis, kg (lb).

$$M_{FTbd} = M_{FTAdb} - M_{FRdb} \quad (2)$$

where:

M_{FTAdb} = total weight of fuel added, dry basis, kg (lb);
M_{FRdb} = weight of fuel remaining in the firebox at end of test, dry basis, kg (lb); and
M_{FTbd} = total weight of fuel burned, dry basis, kg (lb).

$$EF = E_T / M_{FTbd} \quad (3)$$

where:

E_T = total particulate emissions, g (as measured by Test Method E2515); and
EF = emission factor, grams of particulate/dry kg fuel burned.

$$BR = 60(M_{FTbd}/\Theta) \quad (4)$$

where:

Θ = total sampling time, min; and
BR = burn rate, dry kg/h.

$$ER_{HC} = E_T / \Theta_{FI} \quad (5)$$

where:

Θ_{FI} = firing interval time period specified in the builder or manufacturer's written operating instructions and used during testing to operate the masonry heater, h; and
ER_{HC} = the heating cycle emissions rate, g/h.

$$ER_{CP} = 60(E_T/\Theta) \quad (6)$$

where:

ER_{CP} = combustion period emissions rate, g/h.

11. Report

11.1 The report shall include the following:

11.1.1 *Testing Laboratory*—Name and location of the laboratory conducting the test.

11.1.2 *Masonry Heater Identification*—A description of the appliance tested and its condition, date of receipt, and dates of tests. Report masonry heater identification information including builder or manufacturer, model, model line, or design, and serial number of the masonry heater tested. Also include the published installation and operating instructions.

11.1.3 *Model Limitation*—A statement that the test results apply only to the specific appliance tested.

11.1.4 *Reproduction Limitation*—A statement that the test report shall not be reproduced except in full, without the written approval of the laboratory.

11.1.5 *Test Description*—A description of the test procedures.

11.1.6 *Test Conditions*—Details of deviations from, additions to or exclusions from the test method, and information on specific test conditions, such as environmental conditions.

11.1.7 *Roster*—A list of participants and observers present for the tests.

11.1.8 *Firebox:*

11.1.8.1 Data and drawings indicating the fire box size and location of the fuel charge.

11.1.8.2 Drawings and calculations used to determine firebox volume.

11.1.9 *Test Run Data:*

11.1.9.1 Information for each test run fuel charge including piece size, moisture content, and weight.

11.1.9.2 Test run duration for each test.

11.1.9.3 Average results of measurements for flue gas temperature, room temperature, flue gas CO, CO_2, and O_2 concentrations during the test run.

11.1.10 *Test Emission Results:*

11.1.10.1 Calculated results for emissions reported as Total Emissions in grams (E_T), Emissions Factor (*EF*) in grams per kilogram of dry fuel, Heating Cycle Emissions Rate (ER_{HC}) in grams per hour and Combustion Period Emissions Rate (ER_{CP}) in grams per hour.

11.1.10.2 A statement of the estimated uncertainty of measurement of the emissions test results.

11.1.11 *Record Keeping*—Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of seven years.

12. Precision and Bias

12.1 *Precision*—It is not possible to specify the precision of the procedure in this test method (E2817) for measuring masonry heater emissions because it is not feasible to organize an inter-laboratory study that would include a sufficient number of laboratories and product designs to determine reproducibility or repeatability of this measurement method. The products involved are custom built and not moveable from one lab to another and the construction of several models in multiple laboratories is deemed to be cost prohibitive.

12.2 *Bias*—No definitive information can be presented on the bias of the procedure in this test method (E2817) for measuring masonry heater emissions because no product of design having an accepted reference value is known to exist.

13. Keywords

13.1 emissions; masonry heaters; slow heat release appliance; particulate; particulate matter; solid fuel biomass; woodburning

ANNEXES

(Mandatory Information)

A1. CORDWOOD FUEL

INTRODUCTION

In conjunction with Test Method E2515, this test method provides a protocol for laboratory emissions testing of masonry heaters that is intended to simulate actual use in residential homes and other consumer applications. Since such actual use involves almost solely cordwood fueling, Annex A1, Cordwood Fuel, provides as close a simulation as is currently possible of consumer use, and is recommended for predicting actual consumer emissions performance. For regulatory and other potential uses in comparing relative emissions of various masonry heater products and designs, Annex A2, Cribwood Fueling, and Annex A3, Cribwood Fuel, Top-Down Burn, provide optional additional fueling protocols that substitute dimensional lumber cribs for the cordwood fuel. Data that establish the relationships between the emissions results generated by Annex A2 and Annex A3 and the emissions results generated by Annex A1 are not currently available.

A1.1 Scope

A1.1.1 This annex to the test method covers fueling and operating protocol for determining particulate matter emissions from densified, binder free biomass fuel burning masonry heaters using cordwood test fuel. This annex may also be used in conjunction with a future efficiency annex 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, sometimes referred to as "round wood", although, in normal use and in testing practice, it is split into roughly triangular or semi circular segments.

A1.3 Equipment and Supplies

A1.3.1 Same as Test Method E2817.

A1.4 Calibration and Standardization

A1.4.1 Same as Test Method E2817.

A1.5 Main Fuel Load Requirements

A1.5.1 *Fuel Properties:*

A1.5.1.1 *Fuel Species and Properties*—Test fuel charge fuel shall be species of cordwood with a density range of 0.434 to 0.730 g/cm^3 (27 to 46 lb/ft^3) on a dry basis (compare Table A1.1).

A1.5.2 *Fuel Piece Cross Section*—Each fuel piece shall pass through a 153-mm (6-in.) diameter round hole while not

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

Species	Specific Gravity
Douglas Fir	0.43
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
Pecan	0.73
Pine, Southern, longleaf	0.64

passing through a 76-mm (3-in.) diameter round hole. Other piece cross-sections are allowed only if specified in the builder or manufacturer's instructions as furnished to consumers or other end users. Only cordwood pieces that are free of decay, fungus, and loose bark shall be used.

A1.5.3 *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. 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, one reading from within 51 mm (2 in.) of each end and one in the center. The fuel moisture shall be measured using a fuel moisture meter as specified in 7.4. Fuel moisture shall be measured within four hours of using the fuel for a test. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 38°C (100°F).

A1.5.4 *Cordwood Test Fuel Piece Length*—Piece length shall be 407 ± 38 mm (16 ± 1.5 in.) unless otherwise specified by builder or manufacturer. If unspecified and this fuel length is not an appropriate length, the test lab shall make its own judgment.

A1.5.5 *Fuel Load Weight*—The calculated main fuel load volume including fuel pieces and air spaces is equal to 30 ± 5 % of the usable firebox volume. Weight will be determined by species used. If the calculated fuel load weight is below the builder or manufacturer's specified minimum, that specified minimum weight will be used. Similarly, if the calculated fuel load weight exceeds the specified maximum, that specified maximum weight will be used.

A1.5.6 *Placement*—Placement will be in accordance with builder or manufacturer's instructions; lacking such instructions placement will be at the discretion of the lab personnel.

A1.6 Operation

A1.6.1 *Newspaper*—Place the appropriate number of crumpled newspaper balls in the masonry heater in a manner that is consistent with the written operating instructions included with the masonry heater. In the absence of written instructions place the newspaper balls such that they will be evenly distributed under the kindling brand.

A1.6.2 *Kindling*—Record the weight of and then place the kindling fuel in the firebox following the recommendations in the operating instructions. In the absence of recommendation regarding the kindling fuel configuration, kindling piece cross section shall be similar to the cribwood kindling brand, and the total weight shall not exceed 10 % of the weight of the total fuel plus the kindling load weight.

A1.6.3 *Test Beginning*—When all requirements for starting the emissions test are met in accordance with Test Method E2515, record the start time, start the particulate emission sampling equipment and simultaneously ignite the newspaper balls. A propane gas torch has been found to be a good device for obtaining rapid and even ignition of the newspaper. Quickly work your way from one side to the other to ensure even ignition. All newspaper must be ignited within 30 seconds from starting the sampling equipment.

A1.6.4 *Test Ending*—At the end of the test, record the time and all other parameters as required by Test Method E2515 and shut off the emissions measurement equipment. In addition, determine the weight of unburned fuel by shoveling out and weighing all residual fuel and ash. Once weighed, the residue can be placed in the firebox again, and the masonry heater shut down in accordance with the builder or manufacturer's written instructions. This simulates actual usage, during which residues would be used as fuel in the following burn cycle. Record the final residual weight within 5 minutes of the end of the test. A test-burn shall be invalid if less than 90 % of the weight of the total test-fuel charge weight has been consumed in the masonry heater firebox.

A1.7 Data Analysis and Calculations

A1.7.1 *Calculations*—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.

A1.7.2 *Nomenclature:*

$$M_{Kdb} = (M_{Kwb})[100/(100+FM_K)] \tag{A1.1}$$

where:

FM_K = average fuel moisture of kindling fuel dry basis, %;
M_{Kwb} = weight of fuel pieces comprising kindling, wet basis, kg (lb); and
M_{Kdb} = weight of kindling fuel, dry basis, kg (lb).

$$M_{FLdb} = \sum_n (M_{FPnwb})[100/(100+FM_{FPn})] \tag{A1.2}$$

where:

FM_{FPn} = average fuel moisture of each fuel piece n in main fuel load, dry basis, %;
M_{FPnwb} = weight of each fuel piece n in main fuel load, wet basis, kg (lb);
M_{FLdb} = weight of main fuel load, dry basis, kg (lb); and
n = each individual fuel piece comprising the main fuel load as applicable.

$$D_{Kdb} = M_{Kdb}/V_K \tag{A1.3}$$

where:

V_K = combined volume of all fuel pieces comprising the kindling load, cm^3 (ft^3); and

D_{Kdb} = average fuel density of the kindling fuel, dry basis, g/cm^3 (lb/ft^3).

$$D_{FLdb} = M_{FLdb}/V_{FL} \quad (A1.4)$$

where:

V_{FL} = combined volume of all fuel pieces comprising the main fuel load, cm^3 (ft^3); and

D_{FLdb} = density of main fuel load.

$$M_{FTAdb} = M_{Kdb} + \sum M_{FLdb} + M_{CR} \quad (A1.5)$$

where:

M_{CR} = weight of charcoal returned to firebox after pretest warm up or previous test run, kg (lb); and

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

$$M_{FTBdb} = M_{FTAdb} - M_{FRet} \quad (A1.6)$$

where:

M_{FRet} = weight of residual fuel and ash at end of test run, kg (lb); and

M_{FTBdb} = total weight of fuel burned, dry basis, kg (lb).

A1.7.3 *Total Fuel Burned*—If the residual fuel weight at the end of the test in accordance with 9.5.7 is greater than 10 % of the total dry basis fuel weight added at the beginning of the test in accordance with 9.5.3, the test is invalid:

$$\text{If } M_{FRet} > 0.10(M_{FTAdb}), \text{ the test run is invalid.} \quad (A1.7)$$

A2. CRIBWOOD FUELING

INTRODUCTION

In conjunction with Test Method E2515, this test method provides a protocol for laboratory emissions testing of masonry heaters that is intended to simulate actual use in residential homes and other consumer applications. Since such actual use involves almost solely cordwood fueling, Annex A1, Cordwood Fuel, provides as close a simulation as is currently possible of consumer use, and is recommended for predicting actual consumer emissions performance. For regulatory and other potential uses in comparing relative emissions of various masonry heater products and designs, Annex A2, Cribwood Fueling, and Annex A3, Cribwood Fuel, Top-Down Burn, provide optional additional fueling protocols that substitute dimensional lumber cribs for the cordwood fuel. Data that establish the relationships between the emissions results generated by Annex A2 and Annex A3 and the emissions results generated by Annex A1 are not currently available.

A2.1 Crib Construction Procedure

A2.1.1 *Crib Fuel Properties*—The fuel is untreated, standard, or better grade Douglas fir lumber with agency grade stamp: D. Fir or Douglas Fir.

A2.1.1.1 *Fuel Moisture*—The fuel moisture shall be measured using a fuel moisture meter as specified in 7.4. Fuel moisture shall be measured within four hours of using the fuel for a test. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 38°C (100°F).

(1) Kindling Fuel—The average fuel moisture the kindling fuel shall be between 6 % and 12 % Dry Basis. Kiln-dried lumber is permitted for the kindling. Determine fuel moisture for each kindling fuel piece. One moisture meter reading from each piece, measured parallel to the wood grain is sufficient. If an electrical resistance type fuel moisture meter is used, penetration of insulated electrodes shall be ¼ the thickness of the fuel strips. Average all the readings for all the kindling pieces to determine the average fuel moisture for the kindling.

(2) Main Fuel Load—The average fuel moisture for each fuel piece in the main fuel load shall be between 19 % and 25 % Dry Basis. Kiln-dried lumber is not permitted. Kiln-dried lumber is permitted for the spacers. Determine the fuel moisture for each fuel piece (excluding spacers) 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 ¼ the thickness of the fuel piece or 19 mm (¾ in.) whichever is greater.

A2.1.1.2 *Fuel Density*—The average fuel density, dry basis, shall be in the range of 0.434 to 0.546 g/cm^3 (27 to 34 lb/ft^3) for the kindling fuel and for the main fuel load. Nails and spacer pieces are excluded from the density determinations. Determine the total volume of the fuel pieces that comprise (*1*) the kindling load and, (*2*) the main fuel load. Use the wet basis weight and the arithmetically averaged dry basis moisture content to determine the dry basis weight for the kindling and for the individual main fuel load pieces. Determine the dry basis weight for main fuel load by summing the dry basis weight of the individual fuel pieces that comprise the load. Divide the dry basis weight by the volume to determine the density for the kindling and for the main fuel load.

A2.1.2 *Nails*—Use un-coated, un-galvanized nails for assembling kindling brands and main fuel loads. In general, the number of nails used should be limited to the minimum number necessary to hold the fuel load together. The nails should be 18 gauge or smaller nails no longer than 35 mm (1⅜ in.).

A2.1.3 *Total Weight (Dry Basis) of Fuel Added*— Before assembling the kindling load or the main fuel load, record the total weight (wet) of the kindling pieces (without nails) plus the spacers used to construct the fuel load. Using the dry basis moisture determined, determine and record the dry basis weight of the kindling plus spacers. Using dry basis moisture, determine and record the dry basis weight of each fuel piece used in the main fuel load. The total weight of fuel added is the sum of the kindling and spacer dry basis weight plus the dry basis weight of all fuel pieces that comprise the main fuel load. Use the test fuel scale specified in 7.3 for all fuel weight measurements. The kindling and main fuel load must be used within four hours of the moisture and weight measurements.

A2.1.4 *Fuel Length*—Unless otherwise stated by the manufacturer's instructions, the length of kindling and main fuel pieces is determined from the tables following. The tables are based on a near approximation of 67 % of the firebox dimension parallel the piece.

A2.1.5 *Newspaper*—In the absence of specific recommendations for igniting the fuel load in the operating instructions, loosely crumpled balls of full sheets [approximately 4200 cm^2 (650 $in.^2$)] of non-color ink newspaper are used to ignite the fire. [Use one newspaper balls for each 325 cm^2 (50 $in.^2$) of kindling area. The intent is to ensure rapid and even ignition of the fuel load.]

A2.1.6 *Kindling Fuel*—The kindling fuel weight shall be no more than 10 % ± 5 % of the total fuel weight (kindling plus main fuel load) determined on a dry basis without nails.

A2.1.6.1 *Kindling Brand*—In the absence of specific recommendations for the kindling fuel in the operating instructions, a kindling brand is used. The kindling brand is comprised of two layers of 19 mm × 19 mm (¾ in. × ¾ in.) strips and two layers of 19 mm × 38 mm (¾ in. × 1½ in) pieces of Douglas fir that meet the specifications of Section A1.1. The 19 mm × 19 mm (¾ in. × ¾ in.) strips are spaced 19 mm (¾ in.) apart and nailed together. The alternating layers are perpendicular to each other. The 19 mm × 38 mm (¾ in. × 1½ in.) layers are comprised of two pieces in each layer, and create a space for placement of the newspaper balls under the 19 mm × 19 mm (¾ in. × ¾ in.) strips (see Fig. A2.1).

(1) First Layer—The first layer is comprised of two 19 mm × 38 mm (¾ in. × 1½ in.) pieces. The piece length is determined by the usable firebox length (see Table A2.1).

(2) Second Layer—The second layer is comprised of two 19 mm × 38 mm (¾ in. × 1½ in.) pieces. The piece length is determined by the usable firebox width (see Table A2.2).

(3) In addition, four 19 mm × 19 mm × 76 mm (¾ in. × ¾ in. × 3 in) vertical corner fastener pieces are included to facilitate nailing of the first two layers (see Fig. A2.1).

(4) Third Layer—The third layer is comprised of 19 mm × 19 mm (¾ in. × ¾ in.) strips. The length of the strips is determined by the usable firebox length. The number of strips is dependent on the usable firebox width (see Table A2.3).

(5) Fourth Layer—The fourth layer is comprised of 19 mm × 19 mm ¾ in. × ¾ in.) strips. The number of strips is dependent on the usable firebox length (see Table A2.1). The piece length is determined by the usable firebox width (see Table A2.4).

A2.1.7 *Main Fuel Load*—In the absence of specific written operating instructions regarding the composition and placement of the main fuel load, a single default fuel crib is used. This crib is placed on top of the kindling fuel (the kindling fuel may be placed on top if the builder or manufacturer's instructions specify a top down ignition). The crib is comprised of dimensional lumber pieces assembled in a specific pattern with

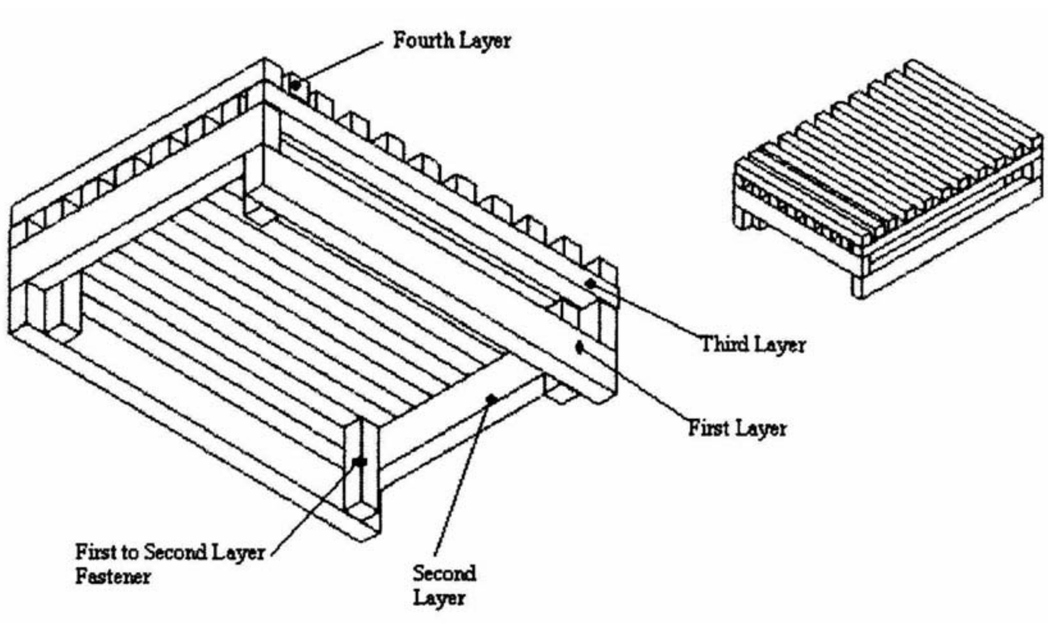

FIG. A2.1 Kindling Brand

TABLE A2.1 Kindling Layer 1

Kindling Fuel — Layer 1 (1 × 2 Material)		
Measured Firebox Length (in.)	Calculated Piece Length (in.)	Actual Piece Length (in.)
12.00	8.00	8 ¼
13.00	8.67	8 ¼
14.00	9.33	9 ¾
15.00	10.00	9 ¾
16.00	10.67	11 ¼
17.00	11.33	11 ¼
18.00	12.00	12 ¾
19.00	12.67	12 ¾
20.00	13.33	12 ¾
21.00	14.00	14 ¼
22.00	14.67	14 ¼
23.00	15.33	15 ¾
24.00	16.00	15 ¾
25.00	16.67	17 ¼
26.00	17.33	17 ¼
27.00	18.00	18 ¾
28.00	18.66	18 ¾
29.00	19.33	18 ¾
30.00	20.00	20 ¼
31.00	20.66	20 ¼
32.00	21.33	21 ¾
33.00	22.00	21 ¾
34.00	22.66	23 ¼
35.00	23.33	23 ¼
36.00	24.00	24 ¾

TABLE A2.2 Kindling Layer 2

Kindling Fuel — Layer 2 (1 × 2 Material)		
Measured Firebox Width (in.)	Calculated Piece Width (in.)	Actual Piece Width (in.)
12.00	8.00	8 ¼
13.00	8.67	8 ¼
14.00	9.33	9 ¾
15.00	10.00	9 ¾
16.00	10.67	11 ¼
17.00	11.33	11 ¼
18.00	12.00	12 ¾
19.00	12.67	12 ¾
20.00	13.33	12 ¾
21.00	14.00	14 ¼
22.00	14.67	14 ¼
23.00	15.33	15 ¾
24.00	16.00	15 ¾
25.00	16.67	17 ¼
26.00	17.33	17 ¼
27.00	18.00	18 ¾
28.00	18.66	18 ¾
29.00	19.33	18 ¾
30.00	20.00	20 ¼

TABLE A2.3 Kindling Layer 3

Kindling Fuel — Layer 3 (¾ × ¾ Strips)			
Measured Firebox Width (in.)	Calculated Brand Width (in.)	Actual Brand Width (in.)	Number of Strips
12.00	8.00	8 ¼	6
13.00	8.67	8 ¼	6
14.00	9.33	9 ¾	7
15.00	10.00	9 ¾	7
16.00	10.67	11 ¼	8
17.00	11.33	11 ¼	8
18.00	12.00	12 ¾	9
19.00	12.67	12 ¾	9
20.00	13.33	12 ¾	9
21.00	14.00	14 ¼	10
22.00	14.67	14 ¼	10
23.00	15.33	15 ¾	11
24.00	16.00	15 ¾	11
25.00	16.67	17 ¼	12
26.00	17.33	17 ¼	12
27.00	18.00	18 ¾	13
28.00	18.66	18 ¾	13
29.00	19.33	18 ¾	13
30.00	20.00	20 ¼	14

TABLE A2.4 Kindling Layer 4

Kindling Fuel — Layer 4 (¾ × ¾ Strips)			
Measured Firebox Length (in.)	Calculated Brand Length (in.)	Actual Brand Length (in.)	Number of Strips
12.00	8.00	8 ¼	6
13.00	8.67	8 ¼	6
14.00	9.33	9 ¾	7
15.00	10.00	9 ¾	7
16.00	10.67	11 ¼	8
17.00	11.33	11 ¼	8
18.00	12.00	12 ¾	9
19.00	12.67	12 ¾	9
20.00	13.33	12 ¾	9
21.00	14.00	14 ¼	10
22.00	14.67	14 ¼	10
23.00	15.33	15 ¾	11
24.00	16.00	15 ¾	11
25.00	16.67	17 ¼	12
26.00	17.33	17 ¼	12
27.00	18.00	18 ¾	13
28.00	18.66	18 ¾	13
29.00	19.33	18 ¾	13
30.00	20.00	20 ¼	14
31.00	20.66	20 ¼	14
32.00	21.33	21 ¾	15
33.00	22.00	21 ¾	15
34.00	22.66	23 ¼	16
35.00	23.33	23 ¼	16
36.00	24.00	24 ¾	17

specific air spaces between the pieces. The total fuel volume plus the number and type of fuel pieces is determined by the usable firebox volume and the hearth or grate width. The dimensional lumber pieces are air-dried Douglas fir that meet the specifications of A2.1.1. The fuel spacer pieces are Douglas fir that meet the specifications of A2.1.1. If the fuel load door opening is of adequate size to allow placement of a fully assembled crib into the firebox, all fuel pieces are nailed together and placed in the firebox as a unit. If the load door opening dimensions do not allow placement of a fully assembled crib into the firebox, the largest possible sections of the crib that will fit through the load door opening are nailed together and the crib sections are then stacked in the firebox to form the full crib.

A2.1.7.1 *Main Fuel Load Volume*—The calculated main fuel load volume including fuel pieces and air spaces is equal to 30 % ± 1.5 % of the usable firebox volume.

A2.1.7.2 *Main Load Fuel Pieces*—Unless otherwise stated by the builder or manufacturer's instructions, length of cribs/fuel pieces, and width of cribs shall be as determined in the following tables (see Table A2.5, Table A2.6, Table A2.7, Table A2.8, Table A2.9).

A2.1.7.3 *Main Load Fuel Piece Layers*—The fuel crib is comprised of one row of "2 × 4" dimensional lumber 38 mm × 89 mm (1½ in. × 3½ in.) and additional full rows or partial rows as needed to achieve the calculated fuel volume of dimensional lumber. The length of each fuel piece is taken

TABLE A2.5 Main Fuel Load Layer 1

Main Fuel Load — Layer 1 (2 × 4's)			
Measured Firebox Width (in.)	Calculated Brand Width (in.)	Actual Layer 1 Width (in.)	Number of 2 × 4's
12.00	8.00	8 ¼	4
13.00	8.67	8 ¼	4
14.00	9.33	8 ¼	4
15.00	10.00	10 ½	5
16.00	10.67	10 ½	5
17.00	11.33	10 ½	5
18.00	12.00	12 ¾	6
19.00	12.67	12 ¾	6
20.00	13.33	12 ¾	6
21.00	14.00	15	7
22.00	14.67	15	7
23.00	15.33	15	7
24.00	16.00	15	7
25.00	16.67	17 ¼	8
26.00	17.33	17 ¼	8
27.00	18.00	17 ¼	8
28.00	18.66	19 ½	9
29.00	19.33	19 ½	9
30.00	20.00	19 ½	9

TABLE A2.6 Main Fuel Load Layers 2 and Higher

Main Fuel Load — Layers 2 and UP (2 × 4's and 4 × 4's)				
Measured Firebox Width (in.)	Calculated Brand Width (in.)	Actual Layer 1 Width (in.)	Number of 2 × 4's	Number of 4 × 4's
12.00	8.00	8	0	2
13.00	8.67	8	0	2
14.00	9.33	8	0	2
15.00	10.00	10 ½	1	2
16.00	10.67	10 ½	1	2
17.00	11.33	10 ½	1	2
18.00	12.00	12 ½	0	3
19.00	12.67	12 ½	0	3
20.00	13.33	12 ½	0	3
21.00	14.00	15	1	3
22.00	14.67	15	1	3
23.00	15.33	15	1	3
24.00	16.00	15	1	3
25.00	16.67	17	0	4
26.00	17.33	17	0	4
27.00	18.00	17	0	4
28.00	18.66	19 ½	1	4
29.00	19.33	19 ½	1	4
30.00	20.00	19 ½	1	4

from the tables according to the parallel usable firebox dimension. The "2 × 4" fuel pieces in the first row are separated horizontally by 19 mm (¾ in.) thick spacers. The spacers are 38 mm (1½ in.) wide × 51 mm (2 in.) long. The "4 × 4" pieces or combined "4 × 4" and "2 × 4" pieces that comprise the second row and above are separated horizontally by 25 mm (1 in.) thick spacers. The spacers are 38 mm (1½ in.) wide × 51 mm (2 in.) long. The "4 × 4"or "2 × 4" and "4 × 4" combined upper rows are separated vertically from the first "2 × 4" row and from each subsequent upper row by 25 mm (1 in.) thick spacers. The spacers are 38 mm (1½ in.) wide. The length of the spacers is equal to the width of the crib (see Fig. A2.2 and Fig. A2.3 for the specific details of construction).

A2.2 Operation

A2.2.1 *Newspaper and Kindling:*

A2.2.1.1 Place the appropriate number of crumpled newspaper balls in the masonry heater in a manner that is consistent with the written operating instructions included with the masonry heater. In the absence of written instructions place the newspaper balls such that they will be evenly distributed under the kindling brand.

A2.2.1.2 Record the weight of and then place the kindling fuel in the firebox following the recommendations in the operating instructions. In the absence of recommendation regarding the kindling fuel configuration, the kindling brand in accordance with A2.1.6 is used. Place the brand above the newspaper balls. The long strips of 19 mm × 38 mm (¾ in. × 1½ in.) kindling fuel should be on the bottom, closest to the masonry heater hearth.

A2.2.1.3 Locate the kindling brand on the grate or on the hearth in accordance with the builder or manufacturer's written instructions that are supplied with the masonry heater, or if no written instructions at the discretion of the testing personnel consistent with A2.1.5 and this section.

A2.2.1.4 If the masonry heater has a grate, center the kindling brand on the grate, both front-to-back and left-to-right (does not apply for grates not intended for fuel placement purposes).

A2.2.1.5 If the masonry heater does not have a grate, center the kindling brand on the firebox hearth, both front-to-back and left-to-right. Without compressing the newspaper balls anymore than absolutely needed, nestle the kindling brand so that it is a level as possible on the newspaper balls.

A2.2.2 *Main Fuel Load:*

A2.2.2.1 In the absence of recommendations in the operating instructions regarding placement of the main fuel load in the firebox, center the main fuel load over the kindling load.

A2.2.2.2 When all requirements for starting the emissions test are met in accordance with Test Method E2515, record the start time, start the particulate emission sampling equipment and ignite the newspaper balls. A propane gas torch has been found to be a good device for obtaining rapid and even ignition of the newspaper. Quickly work your way from one side to the other to ensure even ignition. All newspaper must be ignited within 30 seconds from starting the sampling equipment.

A2.2.2.3 At the end of the test, record the time and all other parameters as required by Test Method E2515 and shut off the emissions measurement equipment. In addition, determine the weight of unburned fuel by shoveling out and weighing all residual fuel, ash and nails. The remaining residue may be extinguished by CO_2 prior to weighing. Record the final residual weight within 5 minutes of the end of the test. The nail weight is considered insignificant and is ignored in the determination of total fuel burned.

A2.3 Data Analysis and Calculations

A2.3.1 *Calculations*—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.

A2.3.2 *Nomenclature:*

TABLE A2.7 Main Fuel Load Height

Main Fuel Load Height (Including 1 in. Vertical Air Space)											
		Row 1	Row 2	Row 3		Row 4		Row 4		Row 6	
Usable Firebox Height (in.)	Calculated Crib Height (in.)	Vertical 2 × 4’s	4 × 4’s or 4 × 4’s and 2 × 4’s	Horizontal 2 × 4’s	4 × 4’s or 4 × 4’s and 2 × 4’s	Horizontal 2 × 4’s	4 × 4’s or 4 × 4’s and 2 × 4’s	Horizontal 2 × 4’s	4 × 4’s or 4 × 4’s and 2 × 4’s	Horizontal 2 × 4’s	Actual Crib Height (in.)
12.00	8.00	X	X								8
13.00	8.67	X	X								8
14.00	9.33	X	X	X							10 ½
15.00	10.00	X	X	X							10 ½
16.00	10.67	X	X	X							10 ½
17.00	11.33	X	X	X							10 ½
18.00	12.00	X	X		X						12 ½
19.00	12.67	X	X		X						12 ½
20.00	13.33	X	X		X						12 ½
21.00	14.00	X	X		X	X					15
22.00	14.67	X	X		X	X					15
23.00	15.33	X	X		X	X					15
24.00	16.00	X	X		X		X				17
25.00	16.67	X	X		X		X				17
26.00	17.33	X	X		X		X				17
27.00	18.00	X	X		X		X				17
28.00	18.66	X	X		X		X	X			19 ½
29.00	19.33	X	X		X		X	X			19 ½
30.00	20.00	X	X		X		X	X			19 ½
31.00	20.66	X	X		X		X		X		21 ½
32.00	21.33	X	X		X		X		X		21 ½
33.00	22.00	X	X		X		X		X		21 ½
34.00	22.66	X	X		X		X		X		21 ½
35.00	23.33	X	X		X		X			X	24
36.00	24.00	X	X		X		X			X	24

TABLE A2.8 Main Fuel Load Alternative Top Layer

Main Fuel Load — Alternative Top Layer (Horizontal 2 × 4’s)			
Measured Firebox Width (in.)	Calculated Brand Width (in.)	Actual Layer Width (in.)	Number of 2 × 4’s Horizontal
12.00	8.00	8	2
13.00	8.67	8	2
14.00	9.33	8	2
15.00	10.00	8	2
16.00	10.67	8	2
17.00	11.33	8	2
18.00	12.00	12 ½	3
19.00	12.67	12 ½	3
20.00	13.33	12 ½	3
21.00	14.00	12 ½	3
22.00	14.67	12 ½	3
23.00	15.33	12 ½	3
24.00	16.00	12 ½	3
25.00	16.67	17	4
26.00	17.33	17	4
27.00	18.00	17	4
28.00	18.66	17	4
29.00	19.33	17	4
30.00	20.00	17	4

$$M_{Kdb} = (M_{Kwb})[100/(100+FM_K)] \quad (A2.1)$$

where:

FM_K = average fuel moisture of kindling fuel dry basis, %;
M_{Kwb} = weight of fuel pieces comprising kindling, excluding nails, wet basis, kg (lb); and
M_{Kdb} = weight of kindling fuel excluding nails, dry basis, kg (lb).

TABLE A2.9 Main Fuel Load Piece Length

Main Fuel Load Piece Length Determination		
Measured Usable Firebox Length (in.)	Calculated Fuel Piece Length (in.)	Actual Fuel Piece Length (in.)
12.00	8.00	8
13.00	8.67	9
14.00	9.33	9
15.00	10.00	10
16.00	10.67	11
17.00	11.33	11
18.00	12.00	12
19.00	12.67	13
20.00	13.33	13
21.00	14.00	14
22.00	14.67	15
23.00	15.33	15
24.00	16.00	16
25.00	16.67	17
26.00	17.33	17
27.00	18.00	18
28.00	18.66	19
29.00	19.33	19
30.00	20.00	20
31.00	20.66	21
32.00	21.33	21
33.00	22.00	22
34.00	22.66	23
35.00	23.33	23
36.00	24.00	24

$$M_{Sdb} = (M_{Swb})[100/(100+FM_S)] \quad (A2.2)$$

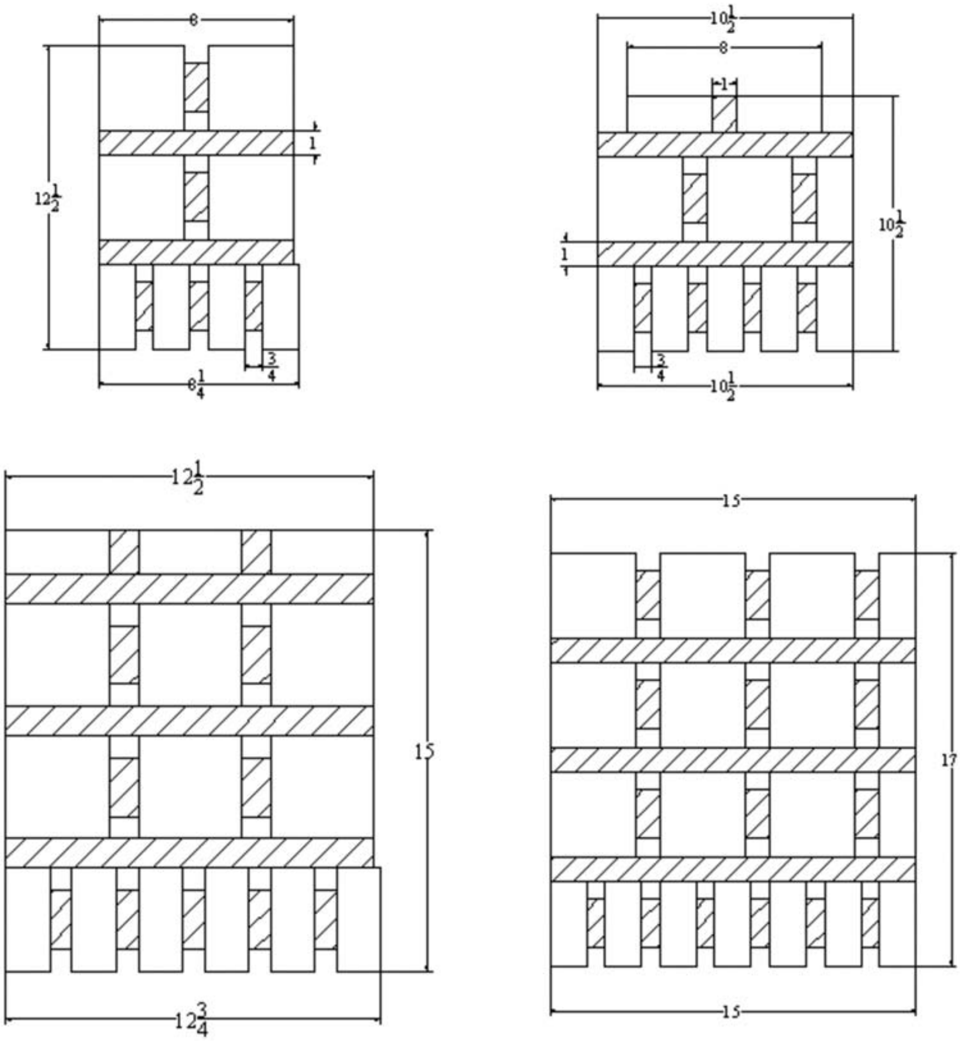

FIG. A2.2 Main Fuel Load Configuration Examples

where:

FM_S = average fuel moisture of the spacers, dry basis, %;
M_{Swb} = weight of all spacers used to construct main fuel load, excluding nails, wet basis, kg (lb); and
M_{Sdb} = weight of all spacers used to construct main fuel load, excluding nails, dry basis, kg (lb).

$$M_{FLdb} = \sum_n (M_{FPnwb})[100/(100+FM_{FPn})] \quad \text{(A2.3)}$$

where:

FM_{FPn} = average fuel moisture of each fuel piece n in main fuel load, dry basis, %;
M_{FPnwb} = weight of each fuel piece n in main fuel load, excluding nails and spacers, wet basis, kg (lb);
M_{FLdb} = weight of main fuel load, excluding nails and spacers, dry basis, kg (lb); and
n = each individual fuel piece comprising the main fuel load as applicable.

$$D_{Kdb} = M_{Kdb}/V_K \quad \text{(A2.4)}$$

where:

V_K = combined volume of all fuel pieces comprising the kindling load, cm^3 (ft^3); and
D_{Kdb} = average fuel density of the kindling fuel, dry basis g/cm^3 (lb/ft^3).

$$D_S = M_{Sdb}/V_S \quad \text{(A2.5)}$$

where:

V_S = combined volume of all the spacers, cm^3 (ft^3) ; and
D_S = average density of the spacers, dry basis, g/cm^3 (lb/ft^3).

$$D_{FLdb} = M_{FLdb}/V_{FL} \quad \text{(A2.6)}$$

where:

V_{FL} = combined volume of all fuel pieces comprising the main fuel load, cm^3 (ft^3); and
D_{FLdb} = density of main fuel load.

$$M_{FTAdb} = M_{Kdb}+M_{Sdb}+M_{FLdb}+M_{CR} \quad \text{(A2.7)}$$

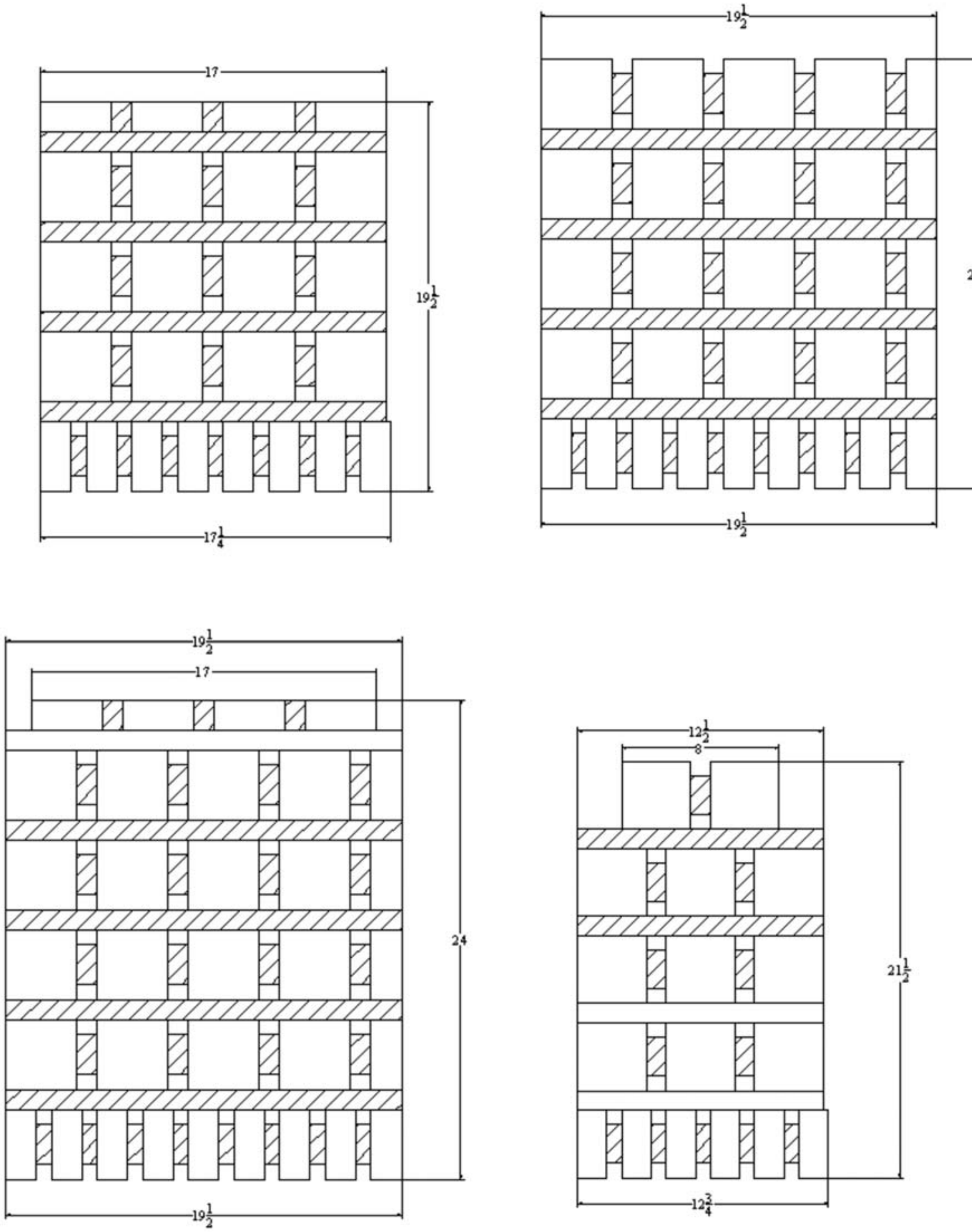

FIG. A2.3 Main Fuel Load Configuration Examples

where:

M_{CR} = weight of charcoal returned to firebox after pretest warm up or previous test run, kg (lb); and

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

$$M_{FTBdb} = M_{FTAdb} - M_{FRet} \quad (A2.8)$$

where:

M_{FRet} = weight of residual fuel, ash and nails at end of test run, kg (lb); and

M_{FTBdb} = total weight of fuel burned, dry basis, kg (lb).

NOTE A2.1—The weight of the nails is considered insignificant and is ignored in the calculation of total fuel weight burned.

A2.3.3 *Total Fuel Burned*—If the residual fuel weight at the end of the test in accordance with 9.5.7 is greater than 10 % of the total dry basis fuel weight added at the beginning of the test in accordance with 9.5.3, the test is invalid:

$$\text{If } M_{FRet} > 0.10(M_{FTAdb})\text{, the test run is invalid.} \quad (A2.9)$$

A3. CRIBWOOD FUEL, TOP-DOWN BURN

INTRODUCTION

In conjunction with Test Method E2515, this test method provides a protocol for laboratory emissions testing of masonry heaters that is intended to simulate actual use in residential homes and other consumer applications. Since such actual use involves almost solely cordwood fueling, Annex A1, Cordwood Fuel, provides as close a simulation as is currently possible of consumer use, and is recommended for predicting actual consumer emissions performance. For regulatory and other potential uses in comparing relative emissions of various masonry heater products and designs, Annex A2, Cribwood Fueling, and Annex A3, Cribwood Fuel, Top-Down Burn, provide optional additional fueling protocols that substitute dimensional lumber cribs for the cordwood fuel. Data that establish the relationships between the emissions results generated by Annex A2 and Annex A3 and the emissions results generated by Annex A1 are not currently available.

A3.1 *Crib Fuel Properties*—The fuel is untreated, standard, or better grade Douglas fir lumber with agency grade stamp: D. Fir or Douglas Fir.

A3.1.1 *Fuel Density*—The average fuel density, dry basis, shall be in the range of 0.434 to 0.546 g/cm^3 (27 to 34 lb/ft^3) for the kindling fuel and for the main fuel load. Nails are excluded from the density determinations. Determine the total volume of the fuel pieces that comprise (*1*) the kindling load, (*2*) the spacers, and (*3*) the main fuel load pieces. Use the wet basis weight and the arithmetically averaged dry basis moisture content to determine the dry basis weight for the kindling, spacers and for the individual main fuel load pieces. Determine the dry basis weight for main fuel load by summing the dry basis weight of the individual fuel pieces that comprise the load. Divide the dry basis weight by the volume to determine the density for the kindling and for the main fuel load.

A3.1.1.1 *Fuel Moisture*—The fuel moisture shall be measured using a fuel moisture meter as specified in 7.4. Fuel moisture shall be measured within four hours of using the fuel for a test. Moisture shall not be added to previously dried fuel pieces except by storage under high humidity conditions and temperature up to 38°C (100°F).

A3.1.1.2 Kindling Moisture – The average moisture content of the pieces in kindling layers shall be between 6.0 % – 12.0 % dry basis. One moisture reading per piece is required.

A3.1.1.3 Spacer Moisture – The average moisture content of the spacer pieces shall be 19 % – 25 % dry basis. One moisture reading per piece is required.

A3.1.1.4 *Fuel Load Piece Moisture*—The average moisture content of each individual fuel piece in the main fuel load shall be 19.0 % – 25.0 % dry basis. Three moisture readings per piece are required; two within 51 mm (2 in.) of separate ends of the piece and one in the middle, each on a different side.

A3.1.2 *Nails*—Use un-coated, un-galvanized nails for assembling kindling and main fuel load layers. In general, the number of nails used should be limited to the minimum number necessary to hold each layer together. The nails should be 18 gauge or smaller nails no longer than 35 mm (1⅜ in.).

A3.1.3 *Total Weight (Dry Basis) of Fuel Added*—Before assembling the kindling load or the main fuel load, record the total weight (wet) of the kindling pieces (without nails) plus the spacers used to construct the fuel load. Using the dry basis moisture determined, determine and record the dry basis weight of the kindling and spacers. Using dry basis moisture, determine and record the dry basis weight of each fuel piece used in the main fuel load. The total weight of fuel added is the sum of the dry basis weight of the kindling and the spacers and all of the fuel pieces that are used to construct the fuel crib. Use the test fuel scale specified in 7.3 for all fuel weight measurements. The kindling and main fuel load must be used within four hours of the moisture and weight measurements.

A3.1.4 *Newspaper*—In the absence of specific recommendations for igniting the fuel load in the operating instructions, loosely crumpled balls of full sheets [approximately 4200 cm^2 (650 $in.^2$)] of non-color ink newspaper are used to ignite the fire. [Use one newspaper balls for each 325 cm^2 (50 $in.^2$) of kindling area]. The intent is to ensure rapid and even ignition of the fuel load.]

A3.1.5 *Kindling Fuel*—The kindling brand portion of the fuel crib forms the top two layers and is composed of layers of 19 mm × 19 mm (0.75 in. × 0.75 in.) strips of Douglas fir that meet the specifications of 3.2.7, 9.4.1, and Section A3.1. The pieces in each layer are spaced 13 mm (0.5 in.) apart and are nailed together so that the top layer is perpendicular to the bottom layer. (See Fig. A3.1.)

A3.1.5.1 *First Layer*—The length of the top layer of kindling pieces is equal to the nominal width of the main portion

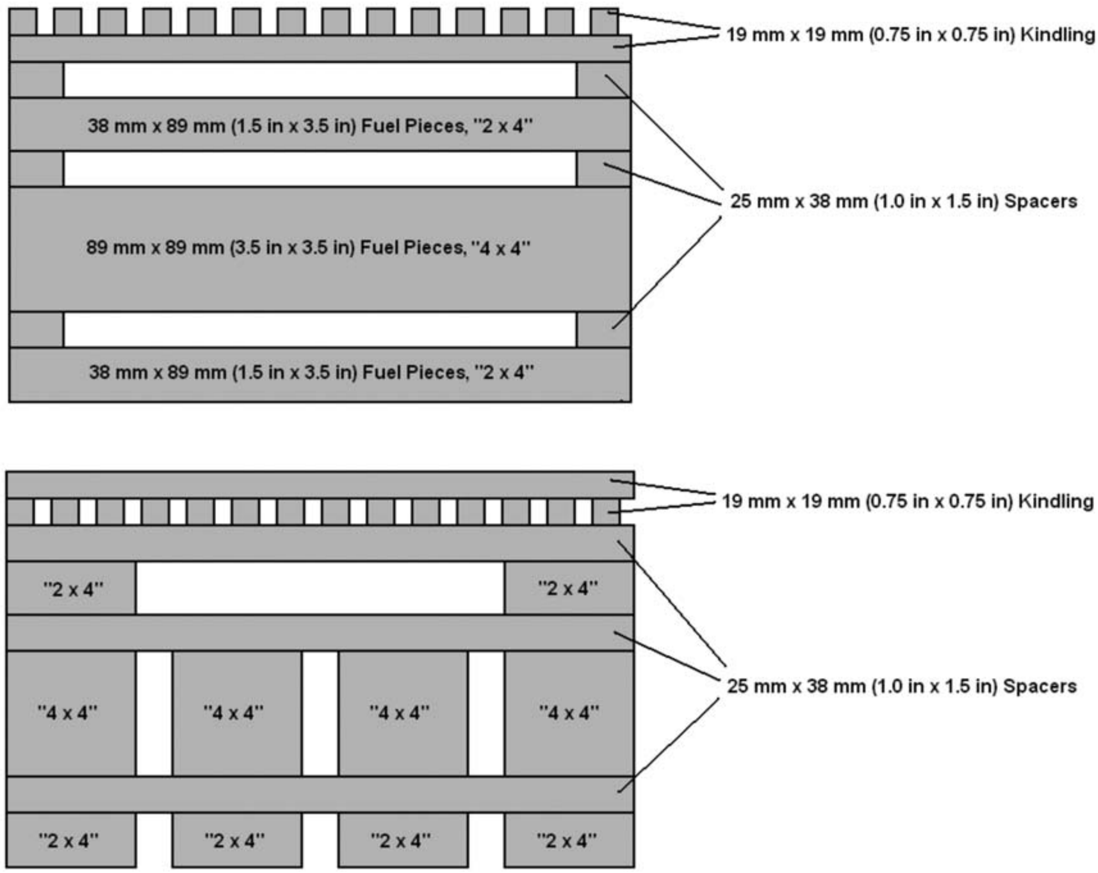

FIG. A3.1 Top Down Burn Crib Kindling/Fuel Arrangement

of fuel crib (see Tables A2.1 and A2.9, Annex A2). The length of the pieces in the top layer can be increased or decreased enough so that the spacing interval is maintained.

A3.1.5.2 *Second Layer*—The length of the second layer of kindling pieces is equal to the nominal length of the pieces in the fuel crib. The length of the pieces in the second layer can be increased or decreased enough so that the spacing interval is maintained

A3.1.5.3 The kindling fuel weight shall be no more than 10 % ± 5 % of the total weight of fuel added (wet basis).

A3.1.6 *Main Portion of the Fuel Crib*—In the absence of specific written operating instructions regarding the composition, configuration and placement of the main portion of the fuel crib, the main portion of the fuel crib is loaded underneath the kindling portion of the fuel crib. The main portion of the fuel crib is comprised of a specific pattern with specific air spaces between the fuel pieces. The total crib volume and the number and type of fuel pieces are both determined by the usable firebox volume and the hearth (or grate) length and width (see Annex A2, A2.1.7). The spacers and fuel pieces in the main portion of the fuel crib are air dried Douglas fir that meet the specifications of Section A3.1. If the fuel loading door opening is of adequate size to allow the placement of a fully assembled layer into the firebox, each fuel layer is nailed together and placed in the firebox layer upon layer starting with the bottom layer. (See Fig. A3.1 and Fig. A3.2.)

A3.1.6.1 *Loading Door Issues*—If the fuel loading door opening will not allow a full layer to be loaded into the firebox, the largest possible section of the crib that will fit through the door are nailed together and the crib sections are then stacked in the firebox to form the full crib. If the builder or manufacturer's written operating instructions or the size of the loading door require that the fuel be inclined when it is loaded in the firebox in order to meet the requirements of A3.1.6.2, the main portion of the fuel load can be inclined when loaded in the firebox and the kindling portion of the fuel crib can be detached from the top and loaded elsewhere. Document the solution thoroughly with photos or in writing, or both.

A3.1.6.2 *Fuel Crib Volume*—The calculated fuel crib volume including fuel and kindling pieces and air spaces is equal to 30 % ± 5 % of the usable firebox volume.

A3.1.6.3 *Main Fuel Load Pieces*—Unless otherwise stipulated by the builder or manufacturer's written instructions, the length of the fuel pieces in the main fuel portion of the fuel crib and the width of the fuel cribs shall be determined as follows:

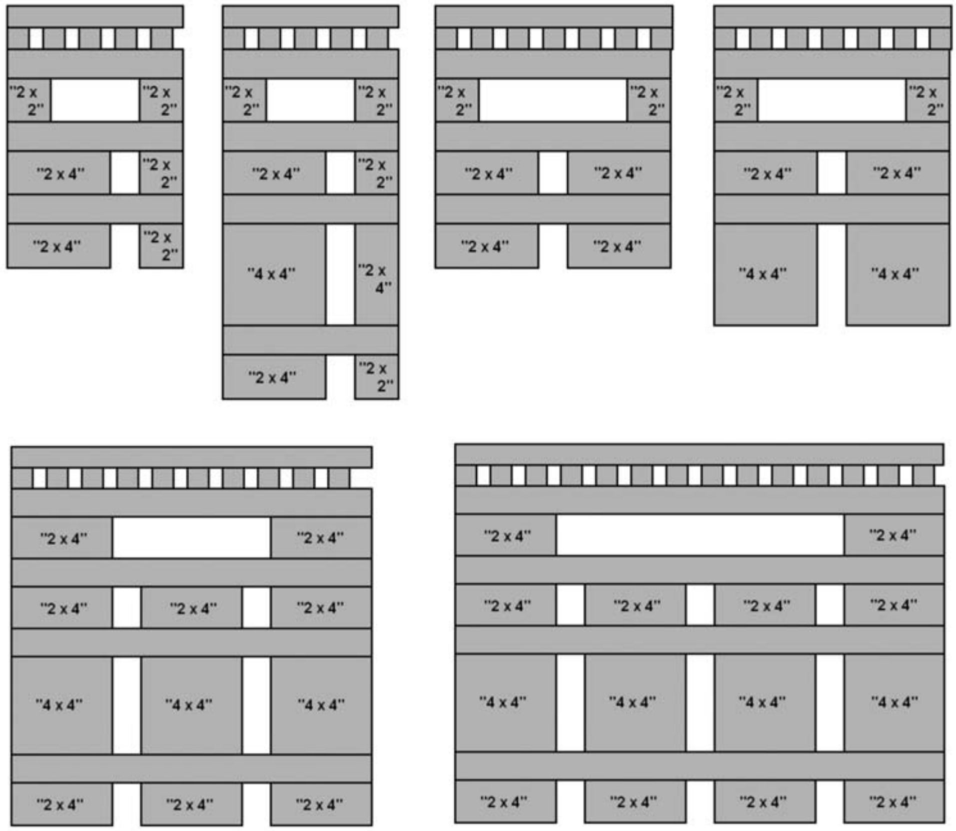

FIG. A3.2 Crib Fuel Load Configuration Examples

(1) Fuel Crib Piece Length—The maximum fuel piece length shall be equal to the firebox length minus 51 mm (2 in.) if the firebox is of uniform length, or if the firebox is not of uniform length, the shortest length dimension minus 51 mm (2 in.). The fuel piece length can be uniformly shortened to meet the fuel load density requirement specified in A3.1.6.2.

(2) Fuel Crib Width—The maximum fuel crib width shall be equal to the largest width fuel crib that can be assembled and fit within the usable firebox volume using "2 × 2", "2 × 4" and "4 × 4" dimensional lumber (see 3.2.14) with a minimum of 2.5 mm (0.5 in.) clearance between the sides of the fuel crib and the side walls of the firebox. The use of "2 × 2"'s is limited to fireboxes with widths that are less than 340 mm (13.5 in.) wide and to one "2 × 2" per layer except for the layer immediately below the kindling brand.

A3.1.6.4 *Fuel Crib Spacers*—The spacers are 25 mm × 38 mm (1 in. × 1½ in.) pieces of air dried Douglas Fir that meet the specifications in Section A3.1. The length of the spacers shall be the nominal width of the main portion of the fuel crib, two spacers per layer. The moisture content shall be 19 % – 25 % dry basis.

A3.1.6.5 Fuel Crib Configuration – The fuel crib configuration is determined by mixing and matching individual "2 × 2" 's, "2 × 4" 's and "4 × 4" 's in order to achieve a calculated fuel crib volume that meets the requirement in A3.1.6.2 and makes it possible to construct a fuel crib that has a height that is less than the height stipulated by the manufacturer to be used in calculating useable firebox volume. The bottom layer in the main portion of a fuel crib shall be either all "2 × 4" 's or "2 × 4" 's and "2 × 2" 's with the 89 mm (3½ in.) dimension loaded parallel to the firebox floor. The vertical spaces between the fuel pieces in the main portion of a fuel crib are all 25 mm (1 in.).

A3.2 Operation

A3.2.1 *Fuel Positioning*—Load the fuel crib layers into the masonry heaters firebox in a manner that is consistent with the written operating instructions included with the masonry heater. When appropriate add the crumpled newspaper balls in the cavity in the main portion of the fuel crib. Then add the kindling brand layer and center it on top of the main portion of the fuel crib.

A3.2.1.1 *Masonry Heaters Without Grates*—If the masonry heater does not have a grate, follow the manufacturer's written instruction for placing the fuel in the firebox. If there are no written instructions, center the fuel crib in the area specified for fuel combustion both left to right and front to back.

A3.2.1.2 *Masonry Heaters With Grates*—If the masonry heater has a grate, center the bottom layer of the fuel crib on the grate, both front-to-back and left-to-right (does not apply for grates not intended for fuel placement purposes).

A3.2.2 *Ignition*—When all requirements for starting the emissions test are met in accordance with both Test Method E2515 and this test method, record the start time and simultaneously start the particulate emission sampling equipment and ignite the newspaper balls. A propane gas torch has been found to be a good device for obtaining rapid and even ignition of the newspaper. Quickly work your way from one side to the other to insure even ignition. All newspaper must be ignited within 30 seconds from starting the sampling equipment.

A3.2.3 *End of Test Run*—At the end of the test, record the time and all other parameters as required by Test Method E2515 and shut off the emissions measurement equipment. In addition within 5 minutes of the end of a test run, determine the weight of unburned fuel by shoveling out and weighing all residual fuel, ash and nails. The remaining residue may be extinguished by CO_2 prior to weighing. Record the final residual weight within 5 minutes of the end of the test. The nail weight is considered insignificant and is ignored in the determination of total fuel burned.

A3.3 Data Analysis and Calculations

A3.3.1 *Calculations*—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.

A3.3.2 *Nomenclature:*

$$M_{Kdb} = (M_{Kwb})[100/(100+FM_K)] \quad \text{(A3.1)}$$

where:

FM_K = average fuel moisture of kindling fuel dry basis %;
M_{Kwb} = weight of fuel pieces comprising kindling, excluding nails, wet basis, kg (lb); and
M_{Kdb} = weight of kindling fuel excluding nails, dry basis, kg (lb).

$$M_{Sdb} = (M_{Swb})[100/(100+FM_S)] \quad \text{(A3.2)}$$

where:

FM_S = average fuel moisture of the spacers, dry basis %;
M_{Swb} = weight of all spacers used to construct main fuel load, excluding nails, wet basis, kg (lb); and
M_{Sdb} = weight of all spacers used to construct main fuel load, excluding nails, dry basis, kg (lb).

$$M_{FLdb} = \sum_n (M_{FPnwb})[100/(100+FM_{FPn})] \quad \text{(A3.3)}$$

where:

FM_{FPn} = average fuel moisture of fuel piece n in main fuel load, % dry basis;
M_{FPnwb} = weight of each fuel piece n in main fuel load, excluding nails and spacers, wet basis, kg (lb); and
M_{FLdb} = weight of main fuel load, excluding nails and spacers, dry basis, kg (lb);
n = each individual fuel piece each comprising the main fuel load as applicable.

$$D_{Kdb} = M_{Kdb}/V_K \quad \text{(A3.4)}$$

where:

V_K = combined volume of all fuel pieces comprising the kindling load, cm^3 (ft^3); and
D_{Kdb} = average fuel density of the kindling fuel, dry basis g/cm^3 (lb/ft^3).

$$D_S = M_{Sdb}/V_S \quad \text{(A3.5)}$$

where:

V_S = combined volume of all the spacers, cm^3 (ft^3) ; and
D_S = average density of the spacers, dry basis, g/cm^3 (lb/ft^3).

$$D_{FLdb} = M_{FLdb}/V_{FL} \quad \text{(A3.6)}$$

where:

V_{FL} = combined volume of all fuel pieces comprising the main fuel load, cm^3 (ft^3); and
D_{FLdb} = density of main fuel load.

$$M_{FTAdb} = M_{Kdb}+M_{Sdb}+M_{FLdb}+M_{CR} \quad \text{(A3.7)}$$

where:

M_{CR} = weight of charcoal returned to firebox after pretest warm up or previous test run, kg (lb); and
M_{FTAdb} = total weight of fuel added excluding nails, dry basis, kg (lb).

$$M_{FTBdb} = M_{FTAdb} - M_{FRet} \quad \text{(A3.8)}$$

where:

M_{FRet} = weight of residual fuel, ash and nails at end of test run, kg (lb); and
M_{FTBdb} = total weight of fuel burned, dry basis, kg (lb).

NOTE A3.1—The weight of the nails is considered insignificant and is ignored in the calculation of total fuel weight burned.

A3.3.3 *Total Fuel Burned*—If the residual fuel weight at the end of the test in accordance with 9.5.7 is greater than 10 % of the total dry basis fuel weight added at the beginning of the test in accordance with 9.5.3, the test is invalid:

$$\text{If } M_{FRet}>0.10(M_{FTAdb}), \text{ the test run is invalid.} \quad \text{(A3.9)}$$