Method For Test-Fueling Residential Wood-Fired Masonry Heaters and Bake Ovens

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1.0 SCOPE

These test-fueling procedures and specifications are for use when measuring the thermal and emissions performance of residential wood-burning masonry heaters and bake ovens. These protocols include specifications for test-period duration, test fuel specifications, test fuel preparation, masonry heater and bake oven operations, and test data-recording requirements.

1.1 Applicability and Principal. The prescribed specifications and procedures contained in these protocols are applicable to the operation and fueling of masonry heaters and bake ovens during thermal efficiency and particulate emissions measurement test periods. The prescribed methods and procedures of these protocols are performed on masonry heaters and bake ovens installed in accordance with their builder's and/or manufacturer's specifications. Specified flue-gas temperature criteria are used to initiate a test period and flue-gas oxygen (O_2) (or alternatively carbon dioxide [CO_2] plus carbon monoxide [CO]) concentration criteria are used for determining fuel re-charging times and test completion. Combustion gases sampled at a standardized sampling location and analyzed for O_2 (or alternatively, CO_2 plus CO) concentrations may be used for calculating the flue-gas flow rates which can, in turn, be used for calculating thermal efficiency and emissions factors.

2.0 DEFINITIONS

Terms as used in these protocols are defined as follows:

Ashpit Loss- The incompletely burned residue left with the ash after a test burn is completed.

Burn Rate — the average rate at which test-fuel is consumed in a masonry heater and bake oven during a test-burn period. The burn rate excludes the inorganic salts and minerals (ie, "ash") and incompletely burned residues or char remaining at the end of a test-burn period; measured in mass of dry wood burned per hour (kg/hour, lb/hour).

Calibration Drift — the difference in an analyzer reading from the initial calibration response at a mid-range calibration value after a stated period of operation during which no maintenance, repair, or adjustment took place.

Calibration Error — 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.

Calibration Gas — a known concentration of carbon dioxide (CO_2), carbon monoxide (CO), and/or oxygen (O_2) in nitrogen (N_2).

Draft Regulator- A device for reducing maximum chimney draft pressures. Draft regulators reduce the potential for over-firing conditions by admitting pressure-relieving

air into the flue connector or chimney duct downstream from the firebox. If a draft regulator is required for safe operation of the appliance, the permanent appliance label and the User's Manual shall contain a statement with the following information:
"For safe operation, a draft regulator (or barometric damper) must be installed in the flue connector or chimney duct of this appliance and shall be adjusted to 0.1 inches of water column (2.5 mm of water column) when the appliance is operated at high-fire conditions."
Effective Flue-Gas Duct Diameter (ED) — for a round flue-gas duct, the actual diameter. For a rectangular flue-gas duct, it is determined using Equation 2.1 as follows:

$$ED = (2 \times (L \times W)) / (L + W) \qquad \textbf{Equation 2.1}$$

Where: **L** = Flue rectangular length.
W = Flue rectangular width.

Flue-Gas Exhaust Duct — the connector pipe, chimney, or other duct form that conveys exhaust gases from the masonry heater and bake oven firebox to the outdoor atmosphere. The flue-gas exhaust duct cross-sectional area is calculated using duct dimensions measured at the narrowest point downstream from the horizontal plane which intersects the top most edge of the fuel loading door (see definition for "Firebox Height" under "Usable Firebox Volume").
Flue-Gas Temperature — 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 or bake oven was closed in accordance with Section 6.7.2.3.

Fuel-Elevating Grate — a non-combustible structure capable of elevating a fuel load above the hearth of a masonry heater or bake oven while offering no, or very little impedance to the passage of combustion air supplies to the bottom of the fuel load and up through the fuel load.

Fuel-Elevating Grate Height — the fuel elevation height above the hearth; the distance between the hearth and a horizontal plane at the bottom of an elevated fuel load.

Fuel Weight, Total — the total weight of the fuel pieces to be used in each fuel-load crib plus spacer and kindling weight.

Hearth Dimensions:

Primary Horizontal Hearth Dimension (PH_{hd}) — for all hearth shapes, the length of a line drawn within the hearth perimeter that is: 1) either a line of hearth plan-view symmetry or the longest line that can be drawn within the hearth perimeter perpendicular to a plan-view line of symmetry and 2) the axis parallel to which fuel-piece lengths are oriented for testing. The masonry heater or bake oven manufacturer or builder shall designate the PH_{hd}, choosing either a line of symmetry or the longest line that can be drawn perpendicular to a line of symmetry, whichever is to be the axis line along which fuel piece lengths are oriented in parallel for burning.

Non-symmetrical hearth shapes — the PH_{hd} shall be designated by the testing laboratory in accordance with the objective of making fuel piece orientation reflect the basic length and width orientation of the hearth within the space intended for fuel placement and burning.

Secondary Horizontal Hearth Dimension (SH_{hd}) — for all hearth area shapes, the length of the longest line that can be drawn within the hearth perimeter perpendicular to the designated PH_{hd}.

Multiple Lines of Symmetry — hearth shapes may have more than one line of symmetry to choose from. The SH_{hd} associated with one PH_{hd} and line of symmetry may not be used for calculating fuel crib dimensions with a PH_{hd} based on a different line of symmetry.

Note: For square and full-circle hearth shapes, the PH_{hd} and SH_{hd} are of equal length.

Horizontal Flue-Gas Pathway — the total net horizontal-duct centerline distance measured from the point where the vertical centerline of the flue-gas exit duct from the firebox intersects the horizontal plane of the firebox height (see definition for "Firebox Height" under "Usable Firebox Volume") to the point where the centerline of the exhaust duct exit to the atmosphere intersects the horizontal plane at the total vertical extent (i.e., height) of the exhaust duct at the flue-gas exit to the atmosphere. For this purpose, horizontal shall mean any amount of duct centerline traverse that is created by any angle that is either more or less than 90º or 270º from vertical.

Internal Assembly — the critical-core construction and firebox design factors that may affect a masonry heater's or bake oven's combustion or heat transfer functions or a masonry heater's or bake oven's particulate emissions factor.

Masonry Heater Association (MHA) – aka; The Masonry Heater Association of North America: www.mha-net.org.

Maximum Flue-Gas Carbon Dioxide Plus Carbon Monoxide Concentration — the difference between the baseline air-supply CO_2+CO concentration (normally 0.00) and the highest 5-minute average data point CO_2+CO concentration measured and recorded during the burning of a test fuel charge.

Maximum Flue-Gas Oxygen Depression — the difference between the baseline air supply oxygen concentration (i.e., 20.9%) and the lowest average 5-minute data point oxygen concentration measured and recorded during the burning of a test fuel charge.

Maximum Masonry-Mass Temperature – is the maximum average masonry-mass temperature rise that occurs after a test has been initiated. The maximum average masonry-mass temperature rise may occur before or after the test burn or test period is completed.

Primary Flue-Gas Sampling and Temperature Measurement Location is within the center 33% of the cross-sectional area of the flue-gas exhaust duct at the point where flue gases either:

1. enter an insulated chimney or chimney connector for discharge to the outdoor atmosphere, or
2. enter that part of the chimney that is outside of the space being heated.

Response Time — the amount of time required for a gas measurement system to respond and display 90% of a step change in the analyte gas concentration.

Sampling System Bias — 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 gas of known concentration is introduced directly to the analyzer.

Span — the upper limit of the gas concentration measurement range. (Typically 25% for CO_2 and O_2, and 5% for CO.)

Test-Burn or Test Period — the time from when flue-gas temperatures rise above 25ºF over the pretest flue-gas temperature after initiation of a test burn to the time flue-gas oxygen concentrations have recovered to at least 95% but not more than 97% of the way back toward ambient oxygen concentrations after the burning of the last of three fuel load charges and the consumption of at least 90% of the total mass of the three consecutively-burned test-fuel charges.

Test Facility — the building enclosure in which the masonry heater or bake oven is installed, operated, and sampled for emissions; includes commercial and residential structures.

Test-Fuel Charge — one of two test-fuel cribs burned during a test period.

Test-Fuel Loading Factor — the ratio between test-fuel crib volume including inter-fuel-piece spacing, and the usable firebox volume. For these protocols, the test-fuel loading factor for masonry heaters is 0.3 (i.e., 30%) and for bake ovens it is 0.2 (i.e. 20%).

***Usable Firebox Volume* (F$_v$)** — the product of the useable hearth area and the average useable firebox height. Useable means the volumetric space within the fire chamber of a masonry heater or bake oven into which fuel can be or is intended to be placed for firing. Usable firebox volume is calculated using the following dimensional definitions:

Firebox Length — average length of at least nine equally-spaced lines running parallel to the greater of 1) the PH_{hd}, or 2) the SH_{hd}.

Firebox Width or Depth — the average length of at least nine equally-spaced lines running perpendicular to the lines used for determining firebox length.

Firebox Floor Versus Hearth Area — if a masonry heater or bake oven has a larger floor area within the fire chamber than the area upon which it is intended that fuel be placed and burned, the useable hearth area shall be calculated as the sum of standard geometric areas or sub-areas of the area intended for fuel placement and burning.

Firebox Height (F_{bh}) — the vertical dimension measured from the hearth of a masonry heater or bake oven, or if present, the top of a fuel-elevating grate to the horizontal plane that intersects and is perpendicular to the top edge of the fuel loading door opening. Alternatively, if fuel is not intended to occupy some of the space below the horizontal plane that intersects and is perpendicular to the top edge of the fuel loading door or is intended to occupy the space above the horizontal plane that intersects and is perpendicular to the top edge of the fuel loading door, the vertical limit of the firebox height shall be delineated by a permanent relief or embossed line, seam, groove, or color demarcation that is easily observed by consumer users.

Fuel-Elevating Grates — for masonry heaters or bake ovens with grates that elevate fuel charges above the hearth, the useable firebox area includes all geometric sub-areas within the total grate area or "foot print" circumscribed by the connection of all of the outer most grate projections. Useable hearth areas calculated using fuel-elevating grate dimensions shall be multiplied by a factor of 1.5 for determining fuel load charge volumes. The volume of test-fuel charges calculated using fuel-elevating grate areas shall not exceed the volume of test-fuel charges calculated using the masonry heater or bake oven hearth area.

Vertical Flue-Gas Pathway — the total vertical duct centerline distance measured from the point where the vertical centerline of the flue-gas exit duct from the firebox intersects the horizontal plane of the firebox height (see definition for "Firebox Height" under “Usable Firebox Volume”) to the point where the centerline of the exhaust duct exit to the atmosphere intersects the horizontal plane at the total vertical extent (i.e., height) of the exhaust duct at the flue-gas exit to the atmosphere. For the purpose of these protocols, horizontal shall mean any amount of duct centerline traverse that is created by any angle that is either more or less than 90º or 270º from vertical. The length of a downward vertical flue-gas pathway is the total sum of all vertical flue-gas pathway distances (upward and downward flow direction) minus the total vertical distance measured from the horizontal plane of the firebox height to the total vertical extent of the flue-gas duct exit to the atmosphere.

Zero Drift — the difference between the initial calibration response at the zero concentration level and the calibration response at the zero concentration level after a stated period of instrument operation during which no maintenance, repair, or adjustment took place.

3.0 TEST APPARATUS

The following test equipment is required for meeting the specifications of these protocols.

3.1 Masonry Heater-Mass, Bake Oven, and Flue-Gas Temperature Sensors. Device(s) capable of measuring flue-gas temperature to within 1.0% of expected absolute temperature values.

3.2 Test Facility Temperature Sensor. A device located centrally in a vertically oriented pipe shield 6 inches (150 mm) long and 2 inches (50 mm) in diameter that is open at both ends and capable of measuring air temperature to within 1.0% of expected absolute temperature values.

3.3 Scale. Electronic strain-gauge scale capable of accurately weighing 220 pound (100 kg) test-fuel charge(s) to within 1.0 pound (0.5 kg).

3.4 Wood-Fuel Moisture Meter. Calibrated Delmhorst® or equivalent electrical resistance meter for measuring test-fuel moisture at a depth of 1 inch (2.5 cm) to within 1% moisture content (dry basis).

3.5 Anemometer. Device capable of measuring air velocities of 20 feet/minute (6.2 m/min), for measuring air velocities near the masonry heater or bake oven being tested.

3.6 Barometer. A barometer capable of measuring atmospheric pressure to within 0.02 inches (0.50 mm) of mercury.

3.7 Draft Gauge. Electro-manometer or inclined liquid manometer for the determination of flue/chimney draft (i.e., static pressure) readable to within 0.02 inches of water column (1.0 Pa).

3.8 Flue-Gas Sample Probe. A stainless-steel probe (304 or better) with $^3/_8$ inch (10 mm) I.D. and at least long enough to reach the center of the flue/chimney at the flue-gas sampling and temperature measurement location as specified in Section 6.3.

3.8.1 Flow Meter. Rotameter with flow-control valve in the 0 to 1 cubic-foot per hour (0 to 500 ml per minute) range.

3.8.2 Condenser/Dryer. Low-volume (i.e., less than 100 ml total volume) Midget glass impinger(s).

3.8.3 Filter. An in-line filter to remove solids and condensable materials from the sampled flue-gas stream. The filter can be fiberglass or glass wool. Disposable filter cartridges may also be used.

3.9 Linear-Measure Device. A standard-verified meter stick or tape measure capable of measuring increments of 0.1 inch (2 mm).

3.10 Vacuum Gages. Vacuum gage with a range of 0 to 30 inches (0 to 760 mm) of mercury.

3.11 Three-Way Valve. For purging and evacuating flue-gas sample lines.

3.12 Gas Analyzers. 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 20.0% and carbon monoxide (CO) in the range of 0.00 to 5.00%. All flue-gas analyzers shall meet the following measurement system performance specifications:

3.12.1 Analyzer Calibration Error. The error shall be ≤ 2% of the span value for the high-range calibration gas used.

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

3.12.3 Zero Drift. The drift shall be ≤ 2% of the high-range span value for the high-range calibration gas used.

3.12.4 Calibration Drift. The drift shall be ≤ 2% of the high-range span value for the high-range calibration gas used.

3.12.5 Analytical Interference. The interference of CO measurements caused by the presence of CO_2 in flue-gases shall be determined by the sampling of high-range CO_2 calibration gas through the carbon monoxide 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.

3.12.6 CO2 Gas Analyzer Accuracy Limitation. If average test-period 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%).

3.13 Sampling Supplies and Reagents.

3.13.1 Calibration Gases. Calibration gases for each flue-gas constituent to be measured shall have concentrations at each of the nominal ranges indicated in Table 3.13.1.1. Mixtures or combinations of calibration gases may be used in place of separate cylinders for each calibration constituent.

Table 3.13.1.1 Nominal Calibration Gas Concentrations

Range	Oxygen	Carbon Dioxide	Carbon Monoxide
High	19 – 21%	17 – 21%	1.0 – 2.5%
Mid	8 - 12%	8 - 12%	0.60 – 1.0%
Low	0 – 4%	0 – 4%	0 – 0.50%

Note 1: All calibration gas mixtures shall be certified by the calibration gas supplier or a laboratory that uses the methods referenced in Title 40 Code of Federal Regulations, Part 60, Appendix A: Methods 3 and 10.

4.0 Fuel

4.1 Species. Test fuel shall be Douglas fir**.**

4.2 Fuel Piece Cross-Sectional Dimensions. For average firebox heights of more than 12 inches (305 mm), test fuel pieces shall consist of air-dried 1.5 x 3.5 inch (38 x 89 mm) and 3.5 x 3.5 inch (89 x 89 mm) actual-dimension lumber.

4.2.1 Small Fireboxes. For average firebox heights equal to or less than 12 inches (305 mm) (e.g., bake ovens), the height of each fuel piece and all vertically positioned fuel crib spacers shall be reduced proportionally to the amount the firebox height is less than 12 inches (305 mm). Adjusted fuel piece and spacer height shall be calculated using Equation 4.2.1.1 as follows:

$$FP_{ah} = FP_{sh} \times AF_h / 12 \text{ inches (305 mm)} \qquad \text{Equation 4.2.1.1}$$

Where: FP_{ah} = Adjusted fuel piece height

FP_{sh} = Standard fuel piece height: 3.5 inches (89 mm)

AF_h = Actual firebox height

FP_{ah} shall be used in the equations in Section 4.2.6.3 for calculating the number of fuel piece layers in each fuel crib.

4.2.2 Fuel Moisture Content. Fuel moisture content is the average of 1 inch deep moisture measurements made at three locations on each fuel piece; one each not closer than 2 inches (51 mm) from each end and one near the middle of the fuel piece length. The average fuel moisture of each fuel piece shall be in the range of 19 to 25% dry basis (16 to 20% wet basis).

Note: Most wood moisture meters measure in dry-basis percent. Verify the moisture meter specifications to confirm its moisture basis measurement type.

4.2.3 Test-Fuel Cribs. Test fuel loads shall be constructed into multi-layered structures referred to herein as “fuel cribs” or “fuel charges”. The overall length, width, and height of fuel cribs are equally proportional to the average length, width, and height of the firebox being tested. Three separate fuel cribs shall be prepared for each test period. The first layer (i.e., the bottom layer) of the first fuel crib shall be made up of 1.5 x 3.5 inch (38 x 89 mm) fuel pieces. The second and higher layers of the first fuel crib, and the entire second and third fuel cribs, are made only of 3.5 x 3.5 inch (89 x 89 mm) fuel pieces. See Figures 4.2.3.1 and 4.2.3.2

4.2.3.1 Spacers. To provide equal spacing between all fuel pieces in a fuel crib, wood spacers with cross-sectional dimensions of 0.75 x 1.5 inches (16 x 38 mm) shall be placed laterally-centered between and on all fuel-piece sides facing other fuel-piece sides. No spacers are to be placed on the outward-facing fuel-crib sides. See Figure 4.2.3.3.

4.2.4 Alternative Fuel Crib Construction. Fuel cribs with component and construction specifications different from those prescribed herein may be approved at the discretion of regulatory jurisdictions specifying this method for regulatory purposes. Alternative fuel crib designs that may be considered include those typically referred to as “top-down”, “rack- or grate-supported full-face”, and/or “air-injection-grate or -rack” burning configurations. Any alternative fuel crib design shall have some means to ensure the structural integrity and stability of two consecutively loaded alternative-design fuel cribs. For example, all of the fuel pieces in each consecutively loaded tepee-design fuel crib shall reasonably remain in the tepee position without any fuel pieces falling out of the primary combustion zone during a test period. Also, it must be demonstrated that the second and third fuel-crib loads can be easily and safely placed in the combustion zone by masonry heater or bake oven users. Alternative fuel-crib designs shall also consist of the same volume/volume fuel loading factor and fuel-piece size distributions as fuel-crib loads specified in the rest of 2.1.4.

Note: It is recommended that a masonry heater or bake oven manufacturer or builder who wishes to use an alternative fueling protocol, test both with the fueling protocol described in Paragraphs 4.2.5 through 4.2.10 and the alternative fueling protocol of their choice.

4.2.5 Fuel Crib Dimensional Specifications. This section describes the procedure by which fuel crib dimensional specifications are determined for hearth perimeters delineated by at least three straight-line walls/sides around the hearth and hearth perimeters having at least one horizontal line of symmetry across the hearth.

4.2.5.1 Fuel Crib Shape. All fuel cribs built to the specifications of this section will have rectilinear plan and length views.

4.2.5.2 Primary and Secondary Horizontal Hearth Dimension Designations (PH_{hd} and SH_{hd}). The manufacturer or builder shall designate either the line of symmetry or the longest line drawn perpendicular to the line of symmetry as the PH_{hd} along which the length of the fuel crib shall be oriented for burning. The longest line perpendicular to the PH_{hd} is designated as the Secondary Horizontal Hearth Dimension (SH_{hd}).

4.2.5.2.1 Line of Symmetry. A line of symmetry is obtained by drawing a straight line across a plan-view drawing of the hearth area, or, if present, the fuel elevating grate area so that the line bisects the hearth or fuel-elevating grate area into mirror images. For hearth or fuel-elevating grate areas that have more than one line of symmetry, only one shall be chosen as the PH_{hd}. This standard makes no preference or specification of which one is chosen.

4.2.5.2.2 Average PH_{hd}. Determine the average PH_{hd} from the lengths of at least nine lines equally spaced and parallel to the PH_{hd} along the whole length of the SH_{hd}.

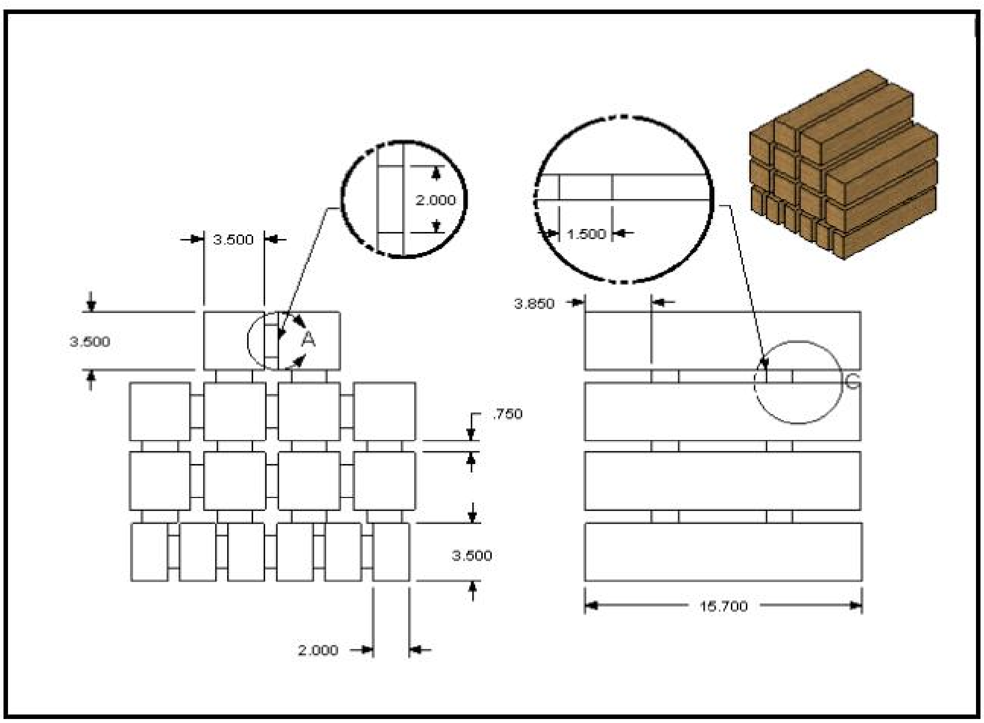

Figure 4.2.5.1: First Fuel-Crib Load Details.

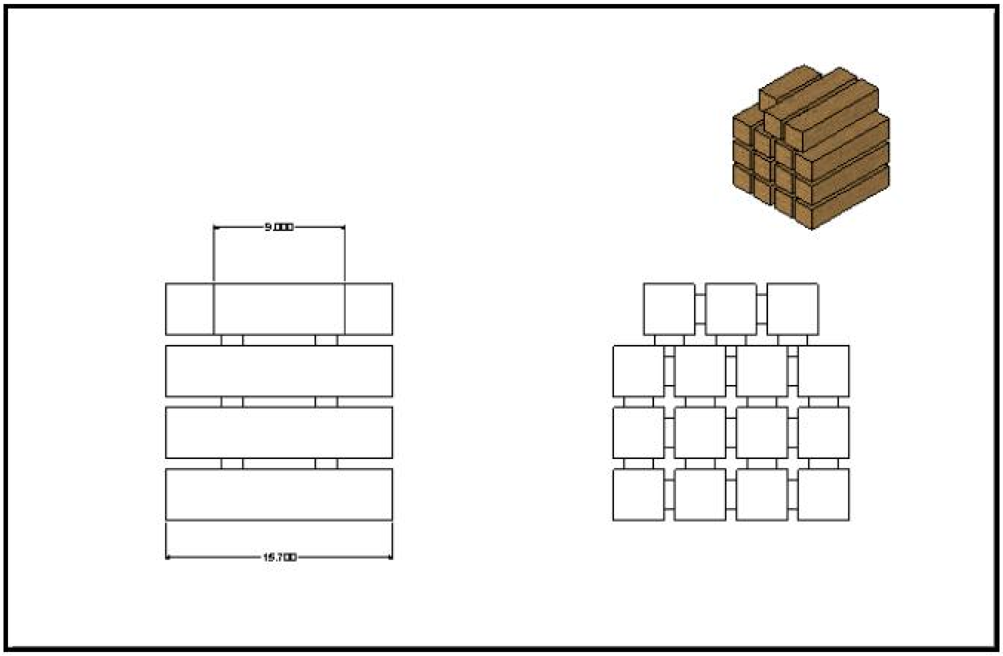

Figure 4.2.5.2: Second and Third Fuel Crib Details.

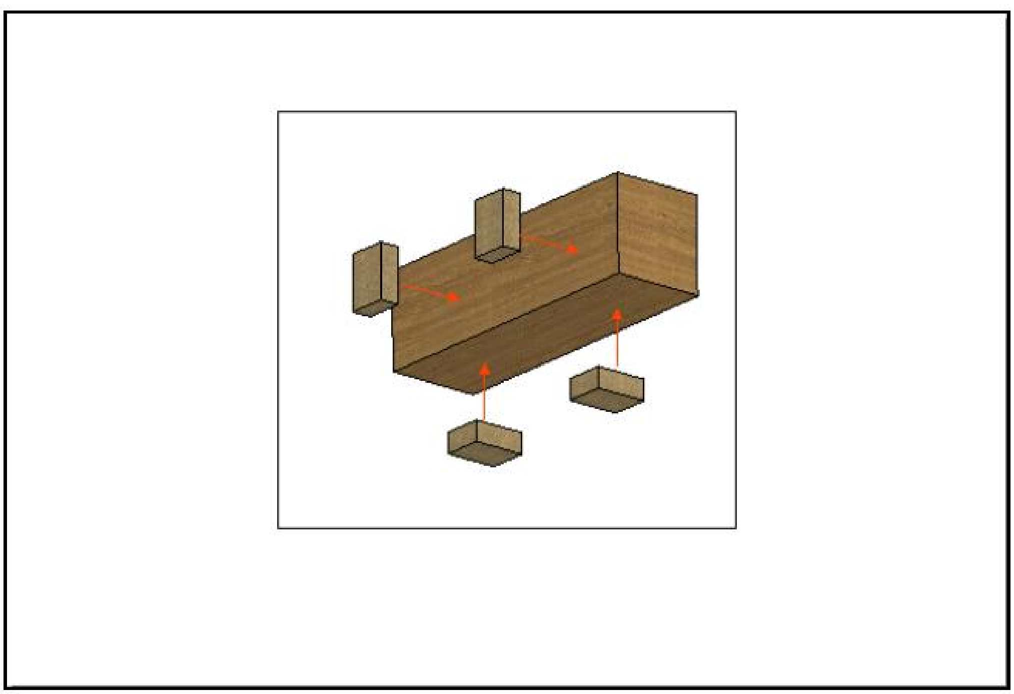

Figure 4.2.5.3: Fuel Piece Spacer Placement.

4.2.5.2.3 Average SH_{hd}. Determine the average SH_{hd} from the lengths of at least nine lines equally spaced and parallel to the SH_{hd} along the whole length of the PH_{hd}.

4.2.5.3 Average Firebox Height (F_{bh}). If there are inwardly slanted or curved firebox walls or other downward physical projections, an average firebox height shall be determined using vertical dimensions measured from the hearth or top of a fuel-elevating grate to the horizontal plane that intersects and is perpendicular to the top of the fuel loading door opening or any lower projection directly above the centers of at least nine closely-equal and square hearth sub-areas, none of which exceeds 16 square inches (100 square centimeters).

4.2.5.4 Total Useable Hearth Area (H_{ua}). Determine the total usable hearth area (H_{ua}) or, if present, the total horizontal plan area of the fuel elevating grate.

4.2.5.5 Useable Firebox Volume (F_v). Calculate useable firebox volume by multiplying the average F_{bh} (or, if applicable, the F_{bha}) by H_{ua}.

4.2.5.6 Fuel-Crib Volume (F_{cv}). Calculate the fuel-crib volume (F_{cv}) as 25% of the F_v.

4.2.5.6.1 Fuel-Elevating Grate. Fuel-crib volume calculated from a fuel-elevating-grate-based H_{ua} (see Fuel-Elevating Grate under the Firebox Volume definition in Section 2.0) shall not be greater than the fuel-crib volume calculated using an H_{ua} derived from the whole useable hearth area.

4.2.5.7 Fuel-Crib Dimension Sizing Factor (FC_{dsf}). Determine the fuel-crib-dimension/firebox-dimension sizing factor as the cube root of the fuel-crib-volume/firebox-volume loading factor.

$$FC_{dsf} = \sqrt[3]{(X/100)}$$ **Equation 4.2.5.7.1**

Where: X = 30% for masonry heaters and 20% for bake ovens,

4.2.5.8 Fuel-Crib Length (FC_l) and Target Fuel-Crib Width (FC_{tw}) and Height (FC_{th}). Determine FC_l, FC_{tw}, and FC_{th} using the following equations:

$$FC_l = PH_{hd} \times FC_{dsf}$$ **Equation 4.2.4.8.1**

$$FC_{tw} = SH_{hd} \times FC_{dsf}$$ **Equation 4.2.4.8.2**

$$FC_{th} = FB_h \times FC_{dsf}$$ **Equation 4.2.4.8.3**

4.2.6 Fuel Piece Spacing. The 0.75 inch (16 mm) vertical and horizontal spacing between parallel fuel pieces shall be made by nailing, with 18 gage x 1¼ inch (32 mm) finishing brads, 0.75 inch x 1.5 inch x 2 inch (16 mm x 38 mm x 51 mm) spacers positioned so their 1.5 inch (38 mm) longitudinal side centerline is 'Y' inches from and parallel to the 3.5 inch (89 mm) end edge of the fuel piece to which it is being attached: Where: Y = 0.15 x F_{pl}. These fuel-piece spacers are further positioned so the latitudinal centerline of the 1.5 x 2 inch (38 x 51 mm) side of the spacer is perpendicular to the longitudinal spacer centerline and 1.75 inches (45 mm) from the longitudinal edge of the fuel-piece side to which it is being attached.

To maintain 0.75 inch (16 mm) spacing between all fuel pieces, spacers should only be attached on alternating facing sides of each fuel piece. No spacers are to be attached to fuel-piece faces located on the outer-most faces of the fuel crib. Maximum spacing between all fuel pieces shall not exceed 0.75 inches (16 mm).

4.2.7 First Fuel-Crib Structure.

4.2.7.1 Number of Fuel Pieces in the Bottom (First) Layer ($n1_1$). The number of bottom/first layer pieces in the first fuel crib is the closest whole number result from Equation 4.2.6.1.1 as follows:

$$n1_1 = (FC_{tw} + 0.75 \text{ inches}) / 2.125 \text{ inches} \qquad \text{Equation 4.2.7.1.1 (in/lb)}$$
$$n1_1 = (FC_{tw} + 1.59 \text{ cm}) / 5.40 \text{ cm} \qquad \text{Equation 4.2.7.1.2 (SI)}$$

Where: **$n1_1$** = Number of fuel pieces in the first layer of the first fuel crib
0.75 inches (1.59 cm) = Place holder for last spacer in each layer
Note: When the result is X.50, round up if the preceding integer, x, is even and down if the integer, x, is odd.

4.2.7.2 Number of Fuel Pieces in Each 3.5 x 3.5 inch (89 x 89 mm) Fuel-Piece Layer ($n1_i$). The number of 3.5 x 3.5 inch (89 x 89 mm) fuel pieces in each of the second, third, and higher layers ($n1_i$) of the first fuel crib and all layers of the second fuel crib, is the closest whole number result from the equation as follows:

$$n1_i = (FC_{tw} + 0.75 + 0.69)/4.125 \text{ inches} \qquad \text{Equation 4.2.7.2.1 (in/lb)}$$
$$n1_i = (F_{tw} + 1.59 + 1.74)/10.48 \text{ cm} \qquad \text{Equation 4.2.7.2.2 (SI)}$$

Where: **$n1_i$** = Number of fuel pieces in the i^{th} layer when 'i' is greater than 1
0.75 inches (1.59 cm) = Place holder for last spacer in each layer
0.69 inches (1.74 cm) = Factor for forcing an additional fuel piece in the event a partial piece of less than 0.333 is calculated.
Note: When the result is X.50, round up if the preceding integer, x, is even and down if the integer, x, is odd.

4.2.7.3 Number of Fuel Crib Layers (n_{fcl}). The number of fuel-crib layers for each and all fuel cribs shall be the closest whole number result from the equation as follows:

$$n_{fcl} = (FC_{th} + 0.75 + 0.69) / (FP_h + 0.75) \qquad \text{Equation 4.2.7.3.1 (in/lb)}$$
$$n_{fcl} = (FC_{th} + 1.59 + 1.74) / (FP_h + 1.59) \qquad \text{Equation 4.2.7.3.2 (SI)}$$

Where: **$n1_{fcl}$** = Number of fuel crib layers
$FP_h = FP_{sh}$ or FP_{ah} (see Section 4.2)
0.75 inches (1.74 cm) = Place holder for last spacer in each layer
0.69 inches (1.59 cm) = Factor for forcing an additional fuel crib layer in the event a partial layer of less than 0.333 is calculated.
Note: When the result is X.50, round up if the preceding integer, x, is even and down if the integer, x, is odd.

4.2.8 Second and Third Fuel-Crib Loads. Except as specified in Section 4.2.1, the second and third fuel-crib loads shall consist entirely of 3.5 by 3.5 inch (89 by 89 mm) fuel pieces nailed and fastened parallel to each other with 0.75 inch (19 mm) spacing between them. The number of pieces in each second fuel-crib layer shall be equal to the number of pieces in the second and higher layers of the first fuel-crib load and the number of layers in each second and third fuel-crib loads shall be equal to the number of layers in the first fuel crib load.

4.2.9 Test-Fuel Crib Construction. All fuel pieces with attached spacers shall be positioned in place to form a rectilinear-shaped fuel crib. All the fuel pieces of the whole fuel crib are then secured in position by wrapping and twist-tying 12 gauge bailing wire around each end of the crib's longitudinal axis. If a fully constructed and bailing-wire-secured fuel crib cannot be safely loaded into the firebox or cannot fit through the test appliance's fuel-loading door, whole fuel-crib layers may be loaded separately starting with the lowest layer and placing subsequently higher layers on top of each other without inter-connecting bailing wire. Only in cases where whole fuel crib layers cannot be placed in the firebox safely or cannot fit through the test appliance's fuel loading door, can fuel crib layers be separated into smaller groups of fuel pieces or individual fuel pieces for loading. In any case, the fuel piece spacing and fuel crib layer and stacking configurations prescribed in this section shall be maintained.

4.2.10 Fuel-Crib Alignment for Testing. Except as provided in 4.2.4, kindling loads and test-fuel-cribs shall be aligned for fuel charging and re-charging so that the lengths of the fuel pieces are parallel to the designated PH_{hd}.

4.2.11 Fuel Crib Weight. Within 30 minutes before testing is initiated, each fuel crib with all their fuel pieces and spacers shall be weighed to the nearest 0.1 lb (45 g) and recorded.

4.2.12 Kindling.

4.2.12.1 Kindling Preparation. For each test, a kindling bed or kindling stack shall be prepared for initiating test fire burning periods. Kindling fuel shall consist of 0.75 x 0.75 inch (19 by 19 mm), 0.75 x 1.5 inch (19 x 38 mm), and 1.5 x 1.5 inch (38 x 38 mm) dimensioned lumber. Kindling fuel species shall be Douglas fir with a moisture content of not more than 15% dry basis. The kindling-fuel load weight is not part of the initial fuel-crib load weight but is in addition to it and is used in calculating total fuel used during a test period. For fireboxes with no fuel-elevating grate, the kindling bed shall consist of four layers of the specified kindling fuel pieces constructed or positioned as follows. See Figure 4.2.12.1.1.

Test Fue
Masonry

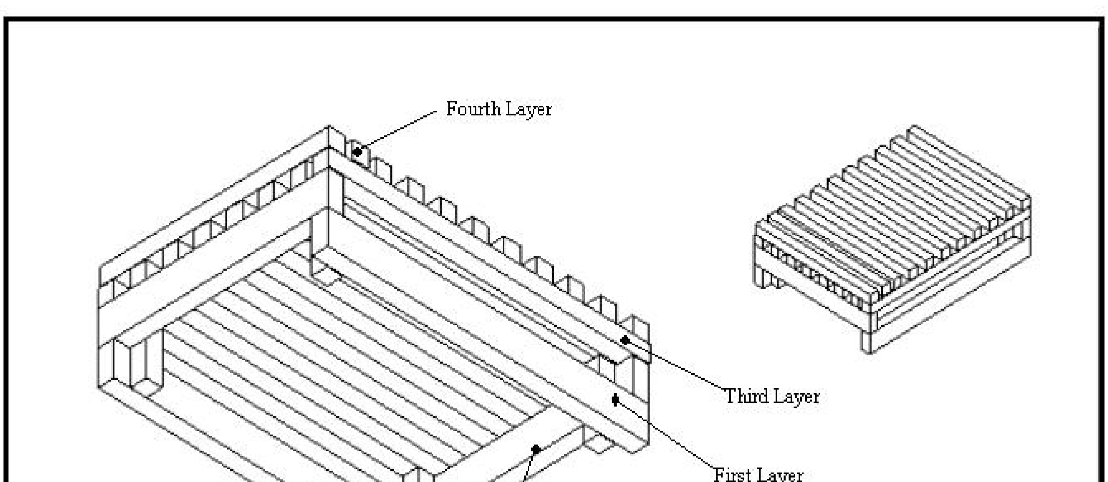

Figure 4.2.12.1.1: Kindling Stack Details.

4.2.12.1.1 First Layer. The first (bottom) kindling layer shall consist of 2 equal-length pieces of the ¾ x 1½ inch (19 x 38 mm) lumber cut to the length dimension of the fuel crib. These two pieces are placed on their ¾ inch (19 mm) edge on the hearth parallel to the PH_{hd}.

4.2.12.1.2 Second Layer. The second kindling layer shall consist of 2 equal-length pieces of the ¾ x 1½ inch (19 x 38 mm) lumber cut to the fuel crib width dimension, placed on their ¾ inch (19 mm) edge on top of the two-piece first layer and perpendicular to the first layer pieces. The ends of the second layer, (i.e., top) two pieces shall be positioned so that the ends of all first- and second-layer pieces meet to form right-angled corners. All first and second layer pieces shall be fastened together at the corners by nailing a 3 inch length of ¾ x ¾ inch (19 x 19 mm) kindling fuel into the inside of each corner using 18 gage by 1¼ inch (32 mm) brads.

4.2.12.1.3 Newspaper. Crumple one full, double-tabloid-width (approximately 650 square inches (4200 cm^2)) of newspaper for every 50 square inches (323 cm^2) of horizontal fuel crib area and place them with even spacing and without excessive compression, within the space created by the first two kindling bed layers.

4.2.12.1.4 Third Layer. The third kindling layer shall consist of ¾ x ¾ inch (19 x 19 mm) lumber cut to equal lengths that are cut to the fuel crib length dimension. Enough of these pieces are prepared so that they can be placed at 1½ inch (38 mm) center-to-center intervals all the way across the top of, and perpendicular to the second layer pieces.

4.2.12.1.5 Fourth Layer. The fourth kindling layer shall consist of the 1½ x 1½ inch (38 x 38 mm) lumber cut to equal lengths that are cut to the fuel crib width dimension. Enough of these pieces are prepared so that they can be placed at 2.5 inch (64 mm) center-to-center intervals all the way across the top of and perpendicular to the third-layer pieces.

4.2.12.2 Firebox with Fuel-Elevating Grate. For fireboxes with a fuel-elevating grate, one layer of 1.5 x 1.5 inch (38 x 38 mm) kindling fuel shall be added to the base 4-layer kindling bed for every 2 inches (51 mm) of fuel elevation above the hearth. Added layers shall be placed perpendicular to the length of the pieces making up the layer immediately below. In the event of a partial 2 inch (50 mm) fuel-elevating grate-height increment, a partial kindling layer shall be prepared. The partial layer shall have a kindling fuel volume directly proportional to the partial height increment of the fuel-elevating grate. For example, a fuel-elevating grate height above the hearth of 3 inches (76 mm) shall have: 3 / 2 (76 mm / 50 mm) = 1.5 additional layers of 1½ x 1½ inch (38 x 38 mm) kindling. The 0.5 partial layer shall have 0.5 of the volume of a whole 1½ x 1½ inch (38 x 38 mm) fuel-piece layer. Partial kindling-layer pieces shall be cut to the same length as full-layer pieces and placed at equal intervals onto the previous layer.

4.2.12.3 Kindling Weight. Within 30 minutes before test initiation, the total weight of all kindling pieces shall be measured to with in 0.1 lb (45 g) and recorded.

5.0 Calibration and Audit Requirements

5.1 Scale. Within three hours before the initiation of a test, the scale used for weighing test-fuel charges shall be audited by weighing at least one calibration weight (Class F) that is in the range of 20% to 80% of the expected test-fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.1 pound (0.05 kg), re-calibrate the scale before use with at least three calibration weights spanning the operational range of the scale.

5.2 Temperature Measurement Devices. Calibrate the temperature measurement devices before the first test period and semiannually thereafter.

5.3 Fuel Moisture Meter. Calibrate the fuel moisture meter in accordance with the manufacturer's instructions within one hour before measuring fuel moisture.

5.4 Anemometer. Calibrate the anemometer in accordance with the manufacturer's instructions before the first test period and semiannually thereafter.

5.5 Barometer. Calibrate the barometer against a mercury barometer before the first test period and semiannually thereafter.

5.6 Draft Gauge. Calibrate the draft gauge in accordance with the manufacturer's instructions before the first test period and semiannually thereafter.

Note: An inclined liquid manometer does not require calibration but must be checked for level (zero tilt) before each test period.

5.7 Sample Gas Flow Meters. Sample gas flow meters shall be calibrated once before the first test period and semiannually thereafter or once after every ten tests whichever occurs first.

5.8 Calibration.

5.8.1 Flue-Gas Analyzers. The oxygen and/or alternatively carbon dioxide plus carbon monoxide analyzers shall be calibrated in accordance with the procedures specified in Section 6.7.12.5 within two hours of test period initiation.

5.9 Sample Flow Rates and System Response Times. The flue-gas sampling (i.e., extraction) rate for instrumental analyses shall be set in accordance with the instrument manufacturer's recommended range within two hours before sampling system response time is measured. The determination of response time for the gas sampling system shall be conducted before the first test period initiation and semiannually thereafter or at any time sampling system flow control components are changed.

5.9.1 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 3.13.1.1) into the sample probe inlet end until the certified calibration gas concentration is measured. After the low range analyte is measured, switch the probe to a high-range calibration gas and immediately start timing the system response time. Response time shall be measured starting at the time the sample probe is switched from the low-range analyte calibration gas to high-range calibration gas and ending at the time the respective analyte analyzer reading is 90% of the difference in calibration gas concentrations utilized.

5.9.2 Response Time Limitation. Response time for all gas-sampling analyzers shall not exceed one minute.

6.0 Test Preparations

6.1 Masonry Heater or Bake Oven Installation. The masonry heater or bake oven being tested must be constructed, if site-built, or, if manufactured, installed in accordance with the designer's/manufacturer's written instructions. These shall be the same instructions provided by the manufacturer or builder to the homeowner/user. The chimney shall have a total vertical height above the hearth of not less than 15 feet (4.6 m) or more than 18 feet (5.5 m). The masonry heater or bake oven chimney exit to the atmosphere must be freely communicating with the masonry heater or bake oven combustion makeup-air source. There shall be no artificial atmospheric pressure differential imposed between the chimney exit to the atmosphere and the masonry heater bake oven make-up air inlet.

6.1.1 Masonry Heaters with More Than One Firebox. Each separately-fired firebox built into a masonry heater structure (e.g., bake ovens) shall be tested separately.

6.2 Masonry Heater and Bake Oven Descriptions. Prepare a written description of the masonry heater or bake oven being tested including any catalyst and/or add-on emissions control devices. The masonry heater or bake oven description shall include photographs showing all externally observable features and drawings showing all internal and external dimensions needed for fabrication and/or construction. The drawings must be verified and certified as representing the tested masonry heater or bake oven by the testing laboratory.

6.3 Primary Flue-Gas Sampling and Temperature Measurement Location. The emissions and flue-gas sampling probes shall draw their flue-gas sample streams from the Primary Flue-Gas Sampling and Temperature Measurement Location and at least six effective flue/chimney duct diameters (as calculated using Equation 2.1) upstream from the flue exit to the atmosphere or 8 feet (2.44 m) above the hearth whichever is the least flue-gas exhaust-duct center line distance from the hearth of the firebox. 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.

6.3.1 Add-On Emission Control Equipment. If a masonry heater or bake oven is equipped with a non-fueled emissions control device located in the flue/chimney duct, downstream from the masonry heater or bake oven firebox, the Primary Flue-Gas Sampling and temperature measurement locations shall be re-positioned immediately downstream from the emissions control device but not less than six effective flue diameters upstream from the flue exit to the atmosphere. A flue-gas sampling and temperature measurement location positioned immediately downstream from an emissions control device shall meet the flue-gas stratification requirements of Section 6.5.2.

6.3.1.1 Fueled Emissions Control Devices. If a masonry heater or bake oven is equipped with an emissions control device that requires additional energy input, except for electricity, the oxygen and/or alternatively the carbon dioxide plus carbon monoxide flue-gas analyzers shall be located at the original Primary Flue-Gas Sampling and temperature measurement location specified in Section 6.3. Test period oxygen and/or carbon dioxide plus carbon monoxide concentrations indicated by this analyzer, upstream from the emissions control device, shall be used for determining fuel recharge and test completion times.

6.4 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 or bake oven. Locate the temperature monitor probe at a distance of 3 to 6 feet (1 to 2 meters) from the front of the masonry heater or bake oven and in a 90º sector defined by lines drawn at ±45º from a perpendicular line to centerline of the masonry heater or bake oven face.

6.5 Heat-Aging, Curing, and Durability Confirmation. A masonry heater or bake oven of any type shall be operated at under "normal" conditions before certification testing begins. Operate the masonry heater or bake oven using the fuel described in Section 4.0 for at least ten hours. Record and report the hours of operation and weight of all fuel burned during the aging, curing and durability confirmation period.

6.5.1 Catalyst And/Or Add-On Emissions Control Device-Equipped masonry heaters or bake ovens**.** Operate a catalyst and/or add-on emissions control-equipped masonry heater or bake oven using fuel described in Section 4.0 for at least 50 hours prior to conducting a test. Record and report hourly catalyst temperatures and add-on emissions control equipment operating parameters during the hours of operation and the weight of all fuel burned during the heat-aging, curing, and durability confirmation period.

6.5.2 Flue-Gas Stratification Check. During the masonry heater or bake oven heat-aging and curing period specified in Section 6.5, use the oxygen analyzer and sampling system specified in Section 3.0 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 Section 6.3.

6.5.2.1 Stratification of Flue-Gas Oxygen Concentrations. The stratification of flue-gas oxygen 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 15 seconds but not more than 1 minute and then sampling within 1 inch (25 mm) of the flue/chimney wall for 15 seconds minimum, 1 minute maximum. This procedure is to be repeated on at least two perpendicular traverses in the horizontal plane of the flue/chimney cross-section. Flue-gas oxygen concentration differences of more than 15% of the highest oxygen concentration measured at any of the other three cross-section sample points shall be considered stratified.

6.5.2.2 Stratification Remedy. The presence of a stratified flue-gas flow regime at the Primary Flue-Gas Sampling Location shall be remedied by either changing the flue/chimney duct design or changing the 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 4 separate and equal areas of the flue/chimney cross-section.

6.6 Leak Check. A leak check of all flue-gas sampling systems shall be performed within two hours before each test period initiation. Leak checks shall be performed as follows.

6.6.1 Leak-Check Procedure. Seal the sample inlet probe-nozzles 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 5 inches (125 mm) 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.

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

6.7 Masonry Heater or Bake Oven Operation and Testing Protocols.

6.7.1 Masonry Heater or Bake Oven Cooling Period. No fuel shall be burned in the masonry heater or bake oven to be tested and no other means for heating the masonry heater or bake oven shall be used within the 12 hour period preceding test period initiation.

6.7.2 Pre-Test-Firing Procedures.

6.7.2.1 Room-Air Velocity. Using an anemometer, measure and record the room-air velocity within 2 feet (0.6 meters) of the test masonry heater or bake oven air supply duct intake or fuel loading door, within one hour before test initiation. Air velocity at the specified locations shall be less than 200 feet/minute (61 m/minute). No external means shall be used to affect air velocities within 2 feet (0.6 meters) of the test masonry heater or bake oven during a test period.

6.7.2.2 Barometric Pressure. Measure and record the barometric pressure within 1 hour before test period initiation.

6.7.2.3 Flue-Gas Temperature Determination. At least one hour before initiating a test period (i.e., ignition of a fire in the masonry heater or bake oven), close all air supply controls and the masonry heater or bake oven fuel loading door(s). After 1 hour of masonry heater or bake oven 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 or bake oven to initiate test-fire ignition, measure and record the pre-test flue-gas temperature at the flue-gas sampling and temperature measurement location or at the upstream temperature measurement location of an emission control device, as provided in Section 6.3.

6.7.3 Test-Burn Ignition. The test burn may be started only with a match (i.e., no charcoal-lighter torches or other devices), with or without paper, and/or with or without kindling. Completion of test-fuel charging shall be within 10 minutes after test initiation as described in Section 6.7.4.

Note: Prior to fuel charge ignition in a masonry heater or bake oven, it may be necessary to first establish an operational flue draft so that combustion gases exit properly through the convoluted venting path and out the chimney exit. Otherwise, initial firebox combustion gases might vent out the fuel-loading door or the fire might extinguish. Establish sufficient operating draft by first heating the venting path by burning paper and/or kindling, so that flue draft is at least 0.02" H_2O measured at the 8 foot (2.44 meter) sampling level. Flue-gas sampling and measurements shall be initiated within 15 seconds of when flue-gas temperatures reach 25ºF above pre-test flue-gas temperature as specified in Section 6.7.2.3. The weight of paper and/or kindling used to initiate a draft for nominal masonry heater or bake oven operation are not considered part of the fuel load charges and are not included in total fuel weight determinations.

6.7.4 Test Period Initiation. Flue-gas sampling is initiated after the kindling and fuel have been ignited and within 15 seconds of when flue-gas temperatures at the center of the flue/chimney at the flue-gas sampling and temperature measurement location, or the upstream flue-gas sampling and temperature measurement location of an emissions control device as provided in Section 6.3, reaches 25ºF (14ºC) greater than the pre-test flue-gas temperature as measured in Section 6.7.2.3.

6.7.5 Test-Time Sampling, Parameter Measurement, and Data Recording Requirements. Once all test sampling and temperature measurements have begun at test initiation in accordance with Section 6.7.4 (i.e., zero time), all test sampling, parameter measurement, and data recording requirements shall be conducted at each 5 minute interval and shall continue without interruption until the test is terminated in accordance with Section 6.7.11. Test-time sampling and temperature measurement parameters shall include:

Oxygen (O_2) and/or CO_2+CO; (see Sections 6.7.7.1 and 6.7.11.1).
Flue-Gas Temperature
All Flue Gas Sample-Train/Sample-System Sampling Rates, and
Draft Pressure at the Primary Sampling and Temperature Measurement Location

6.7.6 Test Facility Ambient Temperatures. Test facility ambient temperatures shall be maintained between 65 and 100ºF (18 and 38ºC) during all test periods.

6.7.7 Test Fuel Additions. Test-fuel crib charges for a test-burn period shall be placed and burned in the fire chamber only after flue-gas oxygen concentrations measured at the Primary Flue-Gas Sampling Location have recovered (i.e., increased) to at least 70% but not more than 80% of the maximum flue-gas oxygen depression value resulting from combustion of the immediately previous kindling or test-fuel charge. 20.9% shall be used as the baseline ambient air supply oxygen concentration. An example of a calculation of the fuel-loading oxygen concentration is as follows: If the **maximum flue-gas oxygen depression** from the burning of a preceding fuel charge was 12.4% (i.e., the minimum flue-gas oxygen concentration during burning of the preceding fuel load was 8.5%: 20.9 – 8.5% = 12.4%), then the following or subsequent fuel charge may only be loaded after the flue-gas oxygen concentration has returned to 17.2% or greater (i.e., (0.7 x 12.4) + 8.5 = 17.2%.) Fuel loading in this example shall be initiated immediately upon measuring the recovery of the flue-gas oxygen concentration to 17.2%. All refueling shall be completed within 10 minutes from when the masonry heater's or bake oven's fuel loading door was opened for refueling.

6.7.7.1 Alternative Fuel Addition Criteria. The recovery of the peak sum of real time flue-gas carbon dioxide and carbon monoxide (CO_2+CO) concentrations back to ambient CO_2+CO concentrations may be used as an alternative to the flue-gas oxygen concentration recovery fuel-load addition/loading criteria. When using CO_2+CO concentrations, test fuel additions shall be placed and burned in the fire chamber only after flue-gas CO_2+CO concentrations have recovered (i.e., decreased) back to at least 30% but not less than 20% of the maximum flue-gas CO_2+CO value resulting from combustion of the immediately previous kindling or test-fuel charge.

6.7.7.2 Inadequate Coal Bed. If the coal bed remaining after flue-gas oxygen concentration has recovered (i.e., increased) to at least 70% of the preceding maximum flue-gas oxygen depression value does not appear to be sufficient or adequate for restarting the next test-fuel charge within the allowed 10 minute fuel-loading period, supplemental newspaper and/or kindling may be added in order to facilitate reasonable ignition of the next fuel-crib load being loaded.

6.7.7.2.1 Loading Supplemental Newspaper and/or Kindling. The addition of all supplemental newspaper and/or kindling used to facilitate the subsequent ignition of the next fuel-crib load plus the loading of the next fuel-crib load shall be completed within the 10 minute fuel-loading period specified in 6.7.7. The weight of all newspaper and/or kindling shall be weighed to the nearest 0.1 lb (0.05 kg), recorded, and added to the total test-fuel weight.

6.7.7.3 Alternative Fuel Charge Burn Pattern. A masonry heater or bake oven may be tested using an alternative fuel-addition procedure that requires the operator to rake the coal-bed to one side of the firebox hearth area before a fuel crib is loaded into the firebox. The objective of this procedure shall be to facilitate a fuel load burn pattern that proceeds from one side of a fuel load toward the opposite side. If a masonry heater or bake oven is tested using this alternative fuel charging procedure an additional permanent label shall be secured in a location on or near the fuel-loading door handle(s) or fuel-loading opening so that it is readily and easily read by consumer users. This label shall state: "**Fuel Loading Shall Only Be Undertaken After The Coal Bed Has Been Safely Raked To The** (*Back, Front, Left or Right* Side: use the side used for testing) **Of The Hearth Area.**" Alternatively, this statement may be added to the "Closed-Door Operation" label specified in Section 6.7.9.

6.7.8 Test-Fuel Charge Adjustments. Test-fuel charges may be adjusted (i.e., repositioned) once during the burning of each test-fuel charge. The time used to make this adjustment shall not exceed 20 seconds.

6.7.9 Combustion Air Supply Adjustment. Any and all means for controlling masonry heater or bake oven combustion air supplies may only be adjusted during each of the 10 minute test-fuel charging periods. At the end of each 10 minute fuel charging period, all air supply control settings must be set to the lowest setting and shall remain at the lowest setting throughout the remaining burn time for each test-fuel charge.

Note: If a masonry heater or bake oven cannot or is not intended to operate at the lowest air supply setting, a permanent instruction label shall be affixed to the masonry heater or bake oven air supply control mechanism as described in Section X.X.X. (yet to be done.)

6.7.10 Auxiliary Masonry Heater or Bake Oven Equipment Operation. Heat exchange blowers (standard or optional) sold with the masonry heater or bake oven shall be operated during all test burns following the manufacturer's or builder's written consumer instruction manual. If no manufacturer's written consumer instruction manual is available, operate the heat exchange blower in the "high" or maximum position. (Automatically operated blowers shall be operated as designed.) Shaker grates, by-pass controls, afterburners, or other auxiliary equipment may be adjusted only once during the period that each test-fuel charge burns, and the adjustment shall be in accordance with the manufacturer's or builder's written instructions. Record and report all adjustments made to auxiliary masonry heater or bake oven equipment during the test period.

6.7.11 Test Completion. A test period (i.e., a two fuel-crib test-burn period) is completed and all sampling and test-period temperature measurements are stopped at the end of the first 5 minute interval after which the flue-gas oxygen concentrations have recovered (i.e., increased) to at least 95% but not more than 97% of the maximum flue-gas oxygen depression value which resulted from combustion of the second test-fuel charge. The ESS and any alternative flue-gas sampling systems shall continue operation after test completion for a period of time equal to the respective response time, as determined in Section 5.9.2, for each flue-gas sampling train/sampling system.

6.7.11.1 Alternative Test Completion Criteria. As with fuel load additions, the recovery of the peak real-time flue-gas carbon dioxide plus carbon monoxide (CO_2+CO) concentrations back toward ambient CO_2+CO concentrations may be used as an alternative to the flue-gas oxygen concentration recovery for test completion criteria: When using CO_2+CO concentrations, test completion shall occur only after flue-gas CO_2+CO concentrations have recovered (i.e., decreased) back down to at least 5% and not less than 3% of the maximum flue-gas CO_2+CO value resulting from combustion of the immediately previous kindling or test-fuel charge. All flue-gas sampling systems shall continue operation after test completion for a period of time equal to their respective response times, as determined in Section 5.9.2, for each sampling train.

6.7.12 Post-Test Procedures.

6.7.12.1 Room-Air Velocities. Using a low-velocity-range anemometer, within 10 minutes after test completion, measure and record the room-air velocity within 2 feet (0.6 meters) of the test masonry heater or bake oven. Air velocity within 2 feet (0.6 meters) of the test masonry heater or bake oven shall not be more than 50 feet/minute (15.4 m/min) without the masonry heater or bake oven operating.

6.7.12.2 Fuel Weight at Test Completion. Within five minutes after test completion, as defined in Section 6.7.11, the remaining coals and/or unburned fuel and/or ash residues shall be carefully removed from the firebox and weighed to the nearest 0.1 pounds (0.05 kg). (It is recommended that the coals first be extinguished with carbon dioxide.) The weight of these unburned materials and ash shall be subtracted from the total test-burn fuel weight when calculating the test period burn rate. A test-burn shall be invalid if less than 90% of the weight of the total test-fuel charges plus the kindling weight has been consumed in the masonry heater or bake oven firebox.

6.7.12.3 Barometric Pressure at Test Completion. Measure and record the barometric pressure within ten minutes after test period completion.

6.7.12.4 Leak Check. The ESS shall be leak checked at the maximum test-period vacuum level within one hour of sampling completion. Under maximum test-period vacuum, the ESS sampling system shall not have a leak rate of more than 2 liters per hour.

6.7.12.5 Combustion-Gas Analyzer Calibrations. To correct analytical accuracy and drift errors, combustion gas analyzers shall be calibrated using the following three-point calibration procedures before and after the analysis of samples for each test period.

- allow the instrument to operate for a sufficient time to stabilize, as recommended by the manufacturer's recommended operating procedures;
- introduce zero gas into the inlet at a “normal” sample flow rate, and zero the analyzer output. Then introduce the high-range calibration gas and span the analyzer output;
- introduce consecutively, in the same manner as described above, the zero and mid-range calibration gases, and record the instrument response to each when no further change in the analyzer response can be detected; and
- calculate and plot a linear least-squares calibration curve, forcing, if necessary, the curve to pass through the origin.

7.0 CALCULATIONS

After test completion, data sheets shall be reviewed for completeness and proper equipment operation. The data sheets, log books, and records maintained by field and laboratory staff shall be reviewed to ensure completeness and readability. Test period data sheets shall be used to calculate masonry heater or bake oven operational parameters.

7.1 Total Test Period and Sampling Time. The total test period sampling time (t_{tt}) in minutes is calculated as follows:

$$t_{tt} = t_c \times N_{T>25^{o}F/\%>97} \qquad \textbf{Equation 7.1.1}$$

Where: t_c = The data-recording cycle (5 minutes for these protocols).

$N_{T>25^{o}F/\%>97}$ = The total number of whole 5 minute data-recording cycles that occurred between the time when the flue-gas temperature after test-burn ignition first exceeded 25EF (14EC) more than the pre-test flue-gas temperature (i.e., test period initiation as defined in Section 6.7.4) and the time when the flue-gas oxygen recovery from the second test-fuel charge reached 95% but not more than 97% (i.e., test period completion as defined in Section 6.7.11).

7.2 Test Period Burn Rate. Burn rate is calculated as follows:

$$\textbf{Burn Rate (kg/hour)} = (\textbf{Total Fuel Weight} \times 60) / t_{tt} \qquad \textbf{Equation 7.2.1}$$

Where: Total Fuel Weight = The dry weight of the total fuel, including spacers and kindling added during the entire test-burn period minus the remaining unburned materials and ash at the end of the test-burn period (kilograms).

7.3 Air-to-Fuel Ratio. The air-to-fuel ratio is calculated using Equation 7.3.1 as follows:

$$A/F_{O2} = \{[42.5/(0.21 - O_2)] \times [0.44 \times (0.21 - O_2) + (0.32 \times O_2) + 0.22]\} - 5.1 \qquad \textbf{Equation 7.3.1}$$

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Where: **A/F** = air-to-fuel ratio expressed as unit mass of air per unit mass of dry wood fuel: lb/lb (kg/kg)
O_2 = mole fraction of oxygen in flue gas (%O_2/100)

7.3.1 Alternate Air-to-Fuel Ratio. If the alternative CO_2+CO flue-gas concentration recovery is used as the criteria for required fuel charging and test completion times instead of oxygen recovery, see Sections 6.7.7.1 and 6.7.11.1, A/F may be calculated using Equation 7.3.1.1 as follows:

$$A/F_{CO2+CO}=\{[42.5/(CO_2+CO)\times[(0.44\times CO_2)+(0.32\times O_2)+0.28\times(N_2+CO)]\}-5.1 \qquad \textbf{Equation 7.3.1.1}$$

7.3.2 Thermal Storage Retention Time. The thermal storage retention time is calculated using the following steps:

7.3.2.1 Average all of the thermal-mass-temperature sensor data for each 10-minute data-recording interval.

7.3.2.2 Record the average thermal-mass-temperature value and the time at which the test burn was initiated.

7.3.2.3 Record the maximum average thermal-mass-temperature value and the time at which it occurred.

7.3.2.4 Record the average thermal-mass temperature value at the 10-minute data-recording interval that occurred 4.00 hours after the maximum thermal-mass-temperature-value was recorded.

7.3.2.5 Subtract the initial average thermal-mass temperature recorded in 7.3.2.2 from the maximum thermal-mass temperature recorded in 7.3.2.3.

7.3.2.6 Subtract the 4.00-hour thermal-mass-temperature value determined in 7.3.2.4 from the maximum average thermal-mass-temperature value determined in 7.3.2.3.

7.3.2.7 Divide the 4.00-hour–maximum thermal-mass temperature differential from 7.3.2.6 by the initial-maximum thermal-mass temperature differential from 7.3.2.5.

7.3.2.8 If the tested appliance conforms to the definition specifications in Section 2.0, and the result from 7.3.2.7 is less than, or equal to 0.50, the appliance qualifies as a "**Masonry Heater**." If the tested appliance conforms to all of the definition specifications in Section 2.0 except that the result from 7.3.2.7 is more than 0.5, the appliance is a fireplace.

8.0 REPORTING REQUIREMENTS

Submit both raw and reduced data for all masonry heater or bake oven tests. All test information and masonry heater or bake oven drawings shall be verified and certified by the testing laboratory that performed the tests being reported. Specific reporting requirements are as follows:

8.1 Masonry Heater or Bake Oven Identification. Report masonry heater or bake oven identification information including manufacturer, model, model line, or design and serial number of the masonry heater or bake oven tested. Also include the published installation and operating instructions.

8.2 Test Facility Information. Report test facility location and test period temperatures and air velocity information.

8.3 Test Equipment Calibration and Audit Information. Report calibration and audit results for the test-fuel scale, test-fuel moisture meter, analytical balance, and sampling equipment including volume metering systems and flue-gas analyzers.

8.4 Pretest Information and Conditions. Report all pretest conditions including test-fuel charge weights, masonry heater or bake oven temperatures, and air supply settings.

8.5 Required Test Report Information and Suggested Format. Test report information requirements are presented in the following recommended report format:

8.5.1 Introduction.

8.5.1.1 Purpose of Test.

8.5.1.2 Masonry Heater or Bake Oven Identification. Manufacturer, model name or number, catalytic/non-catalytic, emissions control equipment, and any optional equipment. Include a copy of masonry heater or bake oven installation and operation manuals.

8.5.1.3 Testing Laboratory. Laboratory name, street and mailing address information, telephone number(s), e-mail contact addresses of key personnel, website address (if existing), and the names of all personnel that performed the testing.

8.5.1.4 Test information. Date masonry heater or bake oven was received, if factory-built, date construction was completed, if site-built, date that each test was conducted, sampling methods used, a description of each masonry heater or bake oven configuration tested as required in Section 6.2, and the number of test burns conducted for each masonry heater or bake oven configuration.

8.5.1.5 Standard Test Method, Masonry Heater, or Bake Oven Operating Protocol Deviations. The report shall contain a complete description of any test method or masonry heater or bake oven operating protocol deviation conducted in the performance of the required test procedures and protocols contained in these protocols. The report must provide detailed rationale explaining the necessity for the deviation(s).

8.6.2 Summary and Discussion of Results.

8.6.2.1 Table of Results. Test-burn identification number, masonry heater or bake oven configuration, burn rate, and air-to-fuel ratio. An example test period summary table is presented in Figures 8.6.2.1.

8.6.2.2 Summary of Other Data. Test facility conditions, surface temperature averages, catalyst temperature averages, test-fuel charge weights, and test-burn times.

8.6.2.3 Discussion. Include specific test-burn problems and solutions and rationale for and for not testing specific configurations like a fuel-elevating grate configuration.

8.6.3 Process Description.

8.6.3.1 Masonry Heater or Bake Oven Dimensions. Firebox height, width, length (or any other pertinent dimensions), weight, and hearth area used for calculating fuel-charge weight.

8.6.3.2 Firebox Internal Assembly Configuration. Include the laboratory-certified verification of the construction or assembly drawings, photographs showing air supply locations and operating mechanisms, combustion air supply pathway(s), refractory materials and dimensions, catalyst location, baffle and/or by-pass configurations and operating mechanisms.

8.6.3.3 Add-On Emissions Control Equipment. If the masonry heater or bake oven utilizes add-on emissions control equipment or a catalytic device for reducing masonry heater or bake oven emissions, provide a complete description of each component including drawings, photographs, and materials used in its construction or production.

8.6.3.4 Masonry Heater or Bake Oven Operation Procedures. Air supply settings and adjustments, fuel-bed/coal-bed adjustments, and draft utilized during each test period.

8.6.3.5 Test Fuel. Test fuel properties including: the volume, weight, and average dry basis moisture content of each fuel load. Also, include photographs of the kindling crib and each fuel load crib.

8.6.4 Sampling Locations. Describe sampling location relative to masonry heater or bake oven components. Include drawings and/or photographs.

8.6.5 Sampling and Analytical Procedures. Include a brief reference to operational and sampling procedures, and optional and alternative procedures used, include details of any parts of the procedures differing from the prescribed methods.

8.6.5.1 Analytical Methods. A brief description of sample recovery and analysis procedures.

8.6.6 Quality Control and Quality Assurance (QC/QA) Procedures and Results

8.6.6.1 Calibration Records. Description of calibration procedures and results.

8.6.6.2 Test Method. Test method quality control procedures: leak-checks, volume-meter checks and sample-blank analyses.

8.6.7 Appendices.

8.6.7.1 Example Calculations. Include complete data tables and accompanying examples of all calculations not performed in the format presented in Section 7.0.

8.6.7.2 Raw Data. Include copies of all original data sheets for sampling records and flue-gas concentration and temperature measurement records. Include copies of all burn-rate and masonry heater or bake oven temperature data.

8.6.7.3 Construction/Assembly Drawings. masonry heater or bake oven construction or assembly drawings which clearly show all dimensions.

8.6.7.4 Sampling and Analytical Procedures. Include detailed description of procedures followed by laboratory personnel in conducting the tests being reported.

8.6.7.5 Calibration Records. Details of all calibrations, checks, and audits pertinent to the reported test results including dates.

8.6.7.6 Participants. Test personnel, manufacturer representatives, and regulatory observers present during testing.

8.6.7.7 Sampling and Operation Records. Copies of original records or logs of activities not included on raw data sheets (e.g., masonry heater or bake oven door-open times and durations).

8.6.7.8 Additional Information. masonry heater or bake oven manufacturer's or builder’s written instructions for operation of the masonry heater or bake oven during the reported test periods and copies of the production-ready (print-ready) permanent user instruction labels required in Section X.X (yet to be done).

8.6.8 References Cited in the Report.

Manufacturer/Builder: *Name*				Test Run Number: #
Test Conducted By: *Laboratory Name* Technician: *Technician Name*				Test Period Start Date/Time: Test Period End Date/Time:
Model Tested: *Model Name/Number*				Configuration: *With/Without F*
Masonry Heater or Bake Oven Type: Catalytic/Non-Catalytic				
Time				**Average Temperatures**
Total Test Period	xx.x	Hours		Flue-Gas Temperature
Test Data Recording Cycle	10.0	Minutes		Test Facility Ambient Temperatur
Fuel				
Total Fuel Used	xx.x	kg wet		**Average Flue-Gas Concentratio**
Average Fuel Moisture	xx.x%	Dry Basis		Oxygen
Total Fuel Burned	xx.x	kg dry		Carbon Dioxide
Average Burn Rate During Operation	x.xx	kg/hour (dry)		Carbon Monoxide

Figure 8.6.2.1 Page 1 of an Example Test-Period Summary Table.