

Test Method 28 OWHH for Measurement of Particulate Emissions and Heating Efficiency of Outdoor Wood-Fired Hydronic Heating Appliances

1.0 Scope and Application

1.1 This test method applies to wood-fired hydronic heating appliances, which the manufacturer specifies for outdoor installation or in structures not normally occupied by humans. The units transfer heat to the indoor environment through circulation of a liquid heat exchange media such as water or a water-antifreeze mixture.

1.2 The test method simulates hand loading of seasoned cordwood and measures particulate emissions and delivered heating efficiency at specified heat output rates based on the appliance's rated heating capacity.

1.3 Particulate emissions are measured by the dilution tunnel method as specified in ASTM Standard Test Method for Determination Of Particulate Matter Emissions Collected In A Dilution Tunnel. Delivered Efficiency is measured by determining the heat output through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance and determining the input from the mass of dry wood fuel and its higher heating value. Delivered efficiency does not attempt to account for pipeline loss.

1.4 Products covered by this test method include both pressurized and non-pressurized heating appliances intended to be fired with wood. These products are wood-fired hydronic heating appliances which the manufacturer specifies for outdoor installation or in structures not normally occupied by humans. They are often connected to an indoor heat exchanger by insulated pipes buried in the ground and normally include a pump to circulate heated liquid. They are used to heat structures such as homes, barns and greenhouses and can heat domestic hot water, spas or swimming pools.

1.5 Distinguishing features of products covered by this standard include:

1.5.1 Manufacturers specifies for outdoor installation or in structures not normally occupied by humans.

1.5.2 A firebox with an access door for hand loading of fuel .

1.5.3 Typically an aquastat that controls combustion air supply to maintain the liquid in the appliance within a predetermined temperature range provided sufficient fuel is available in the firebox.

1.5.4 A chimney or vent that exhausts combustion products from the appliance.

1.6 The values stated are to be regarded as the standard whether in I-P or SI units. The values given in parentheses are for information only.

2.0 Summary of Method and References

2.1 Particulate matter emissions are measured from a wood– fired hydronic heating appliance burning a prepared test fuel crib in a test facility maintained at a set of prescribed conditions. Procedures for determining burn rates, and particulate emissions rates and for reducing data are provided.

2.2 Referenced Documents

2.2.1 EPA Standards

2.2.2 40 CFR Part 60 Subpart AAA, Method 5G

2.2.3 Method 28 Certification and Auditing of Wood Heaters

2.2.4 ASTM Standard Test Method for Determination Of Particulate Matter Emissions Collected In A Dilution Tunnel.

2.2.5 ASTM E711 – Standard Test Method for Gross Value of Refuse-Derived Fuel by the Bomb Calorimeter.

2.2.6 CAN/CSA-B415.1-00 Performance Testing of Solid-Fuel-Burning Heating Appliances

3.0 Terminology

3.1 Definitions

3.1.1 Hydronic Heating – A heating system in which a heat source supplies energy to a liquid heat exchange media such as water that is circulated to a heating load and returned to the heat source through pipes.

3.1.2 Aquastat – A control device that opens or closes a circuit to control the rate of fuel consumption in response to the temperature of the heating media in the heating appliance.

3.1.3 Delivered Efficiency – The percentage of heat available in a test fuel charge that is delivered to a simulated heating load as specified in this test method. This test does not account for jacket losses or for transfer line losses which will vary with actual application.

3.1.4 Manufacturer's Rated Heat Output Capacity – The value in BTU/hr (MJ/hr) that the manufacturer specifies a particular model of hydronic heating appliance is capable of supplying at its design capacity as verified by testing, in accordance with Section 13.

3.1.5 Burn rate – The rate at which test fuel is consumed in an appliance. Measured in lbs of wood (dry basis) per hour (kg/hr).

3.1.6 Firebox – The chamber in the appliance in which the test fuel charge is placed and combusted.

3.1.7 Test fuel charge – The collection of Test Fuel layers placed in the appliance at the start of the emission test run.

3.1.8 Test Fuel Layer – Horizontal arrangement of Test Fuel Units.

3.1.9 Test Fuel Unit – One or more Test Fuel Pieces with $\frac{3}{4}$ inch (19mm) spacers attached to the bottom and to one side. If composed of multiple Test Fuel Pieces, the bottom spacer may be one continuous piece.

3.1.10 Test Fuel Piece – A single 4 x 4 (4 ± 0.25 inches by 4 ± 0.25 inches)[100 ± 6 mm by 100 ± 6 mm] white or red oak wood piece cut to the length required.

3.1.11 Test Run – An individual emission test which encompasses the time required to consume the mass of the test fuel charge.

4.0 Summary of Test Method

4.1 Dilution Tunnel. Emissions are determined using the “dilution tunnel” method specified in ASTM Standard Test Method For Determination Of Particulate Matter Emissions Collected In A Dilution Tunnel. The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high efficiency filters. The filters are dried and weighed before and after the test to determine the emissions catch and this value is multiplied by the ratio of tunnel flow to filter flow to determine the total particulate emissions produced in the test cycle.

4.2 Efficiency. The efficiency test procedure takes advantage of the fact that this type of appliance delivers heat through circulation of the heated liquid (water) from the appliance to a remote heat exchanger and back to the appliance. Measurements of the water temperature difference as it enters and exits the heat exchanger along with the measured flow rate allow for an accurate determination of the useful heat output of the appliance. The input is determined by weight of the test fuel charge, adjusted for moisture content, multiplied by the Higher Heating Value.

Additional measurements of the appliance weight and temperature at the beginning and end of a test cycle are used to correct for heat stored in the appliance.

4.3 Operation. Appliance operation is conducted on a hot-to-hot test cycle meaning that the appliance is brought to operating temperature and a coal bed is established prior to the addition of the test fuel charge and measurements are made for each test fuel charge cycle. The measurements are made under constant heat draw conditions within pre-determined ranges. No attempt is made to modulate the heat demand to simulate an indoor thermostat cycling on and off in response to changes in the indoor environment. Four test categories are used. These are:

4.3.1 Category I: A heat output of 15% or less of Manufacturer's Rated Heat Output Capacity.

4.3.2 Category II: A heat output of 16% to 24% of Manufacturer's Rated Heat Output Capacity.

4.3.3 Category III: A heat output of 25% to 50% of Manufacturer's Rated Heat Output Capacity.

4.3.4 Category IV: Manufacturer's Rated Heat Output Capacity.

5.0 Significance and Use

5.1 The measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

5.1.1 These measurements, when approved by state or federal agencies, are often required for the purpose of determining compliance with regulations and statutes.

5.1.2 The measurements made before and after design modifications are necessary to demonstrate the effectiveness of design changes in reducing emissions and make this standard an important tool in manufacturer's research and development programs.

5.2 Measurement of heating efficiency provides a uniform basis for comparison of product performance that is useful to the consumer. It is also required to relate emissions produced to the useful heat production.

5.3 This is a laboratory method and is not intended to be fully representative of all actual field use. It is recognized that users of hand-fired wood burning equipment have a great deal of influence

over the performance of any wood-burning appliance. Some compromises in realism have been made in the interest of providing a reliable and repeatable test method.

6.0 Apparatus

6.1 Scale. A platform scale capable of weighing the appliance under test and associated parts and accessories when completely filled with water to an accuracy of ± 1.0 pound (± 0.5 kg).

6.2 Heat exchanger. A water-to-water heat exchanger capable of dissipating the expected heat output from the system under test.

6.3 Temperature Difference Measurement. Thermocouples or a thermopile installed in thermowells shall be used to measure the temperature difference in water entering and leaving the heat exchanger. The temperature difference measurement shall have an uncertainty of ± 0.50 °F (± 0.25 °C).

6.4 Water flow meter. Water flow meters shall be installed on both the appliance side and the load side of the heat exchanger.

6.4.1 Appliance side water flow meter. A totalizing type water flow meter with a resolution of 0.1 gallon (0.025 L) and an accuracy of 2% of volume recorded or a flow meter with an accuracy of ± 0.1 gal/min (± 0.025 L/min).

6.4.2 Load side water meter. A totalizing type water flow meter with a resolution of 0.1 gallon (0.025 L) and an accuracy of 0.5% of volume recorded or a flow meter with an accuracy of ± 0.01 gal/min (± 0.0025 L/min).

6.5 Recirculation Pump. Circulating pump used during test to prevent stratification of liquid being heated.

7.0 Safety

7.1 These tests involve combustion of wood fuel and substantial release of heat and products of combustion. The heating system also produces large quantities of very hot water and the potential for steam production and system pressurization. Appropriate precautions must be taken to protect personnel from burn hazards and respiration of products of combustion.

8.0 Sampling, Test Specimens and Test Appliances

8.1 Test specimens shall be supplied as complete appliances including all controls and accessories necessary for installation in the test facility. A full set of specifications and design and assembly drawings shall be provided when the product is to be placed under certification of a third-party agency. The manufacturer's written installation and operating instructions are to be used as a guide in the set-up and testing of the appliance.

9.0 Preparation of Apparatus

9.1.1.1 The appliance is to be placed on a scale capable of weighing the appliance fully loaded with a resolution of ± 1.0 lb (0.5 kg).

9.1.1.2 The appliance shall be fitted with the type of chimney recommended or provided by the manufacturer and extending to 15 ± 0.5 feet (4.6 ± 0.15 m) from the upper surface of the scale. If no flue or chimney system is recommended or provided by the manufacturer, connect the appliance to a flue of a diameter equal to the flue outlet of the appliance. The flue section from the appliance flue collar to 8 ± 0.5 feet above the scale shall be single wall stove pipe and the remainder of the flue shall be double wall insulated class A chimney.

9.1.1.3 A recirculation pump shall be installed between connections at the top and bottom of the appliance to minimize thermal stratification. The pump shall not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger.

9.1.1.4 Prior to filling the tank, weigh and record the appliance mass.

9.1.1.5 Plumb the unit to a water-to-water heat exchanger with sufficient capacity to draw off heat at the maximum rate anticipated. Route hoses and electrical cables and instrument wires in a manner that does not influence the weighing accuracy of the scale as indicated by placing dead weights on the platform and verifying the scale's accuracy.

9.1.1.5.1 Locate thermocouples to measure the water temperature at the inlet and outlet of the heat exchanger in the supply line and return line from Appliance being tested. Also install a calibrated water flow meter. The reported efficiency and heat output rate shall be based on measurements made on the appliance side of the system. If temperature differences are expected to be small, a differential thermopile should be used to measure the water differential temperature. The average of the outlet and return water temperature on the supply side of the system shall be considered the average appliance temperature for calculation of heat storage in the appliance (**TF** and **TI**). (See Figures 2 and 3.)

9.1.1.5.2 Temperature and flow meter instrumentation shall be installed in the output and return lines from the cooling water system as a secondary check on the results. The water flow meter is to be installed on the cooling water inlet side of the heat exchanger so that it will operate at the same temperature as its calibration. Place the heat exchanger in a box with 2 inches (50mm) of **EPS** foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.1.1.6 Fill the system with water. Determine the total weight of the water in the appliance when the water is circulating. Verify that the scale indicates a stable weight under operating conditions. Make sure air is purged properly.

10.0 Calibration and Standardization

10.1 Temperature Sensors. Temperature measuring equipment shall be calibrated to NIST traceable standards at least once every six months.

10.2 Water Flow Meter. The water flow meter shall be calibrated using NIST Traceable methods at least once every six months.

10.3 Scales. The scales used to weigh the appliance and test fuel charge shall be calibrated using NIST Traceable methods at least once every 6 months.

10.4 Moisture Meter. The moisture meter shall be calibrated per the manufacturer's instructions and checked before each use.

11.0 Conditioning

11.1 Prior to testing, the non-catalytic appliance is to be operated for a minimum of 10 hours using a medium heat draw rate. Catalytic units shall be operated for a minimum of 50 hours using a medium heat draw rate. The pre-burn for the first test can be included as part of the conditioning requirement. If conditioning is included in pre-burn, then the appliance shall be aged with fuel meeting the specifications outlined in Sections 13.2 with a moisture content between 19 and 25 percent on a dry basis. Operate the appliance at a medium burn rate (Category II or III) for at least 10 hours for non-catalytic appliances and 50 hours for catalytic appliances. Record and report hourly flue gas exit temperature data and the hours of operation. The aging procedure shall be conducted and documented by a testing laboratory.

12.0 Procedure

12.1 Appliance Installation. Assemble the appliance and parts in conformance with the manufacturer's written installation instructions. Clean the flue with an appropriately sized, wire chimney brush before each certification test series.

12.2 Fuel. Test fuel charge fuel shall be red (*Quercus rubra* L.) or white (*Quercus Alba*) oak 19 to 25% moisture content on a dry basis. Piece length shall be 80% of the firebox depth rounded down to the nearest 1 inch (25mm) increment. For example, if the firebox depth is 46 inches (1168mm) the 4 x 4 piece length would be 36 inches (46 inches x 0.8 = 36.8 inches round down to 36 inches. Pieces are to be placed in the firebox parallel to the longest firebox dimension. For fireboxes with sloped surfaces that create a non-uniform firebox length, the piece length shall be adjusted for each layer based on 80% of the length at the level where the layer is placed. Pieces are to be spaced $\frac{3}{4}$ inches (19mm) apart on all faces. The first fuel layer may be assembled using fuel units consisting of multiple 4 x 4's consisting of single pieces with bottom and side spacers of 3 or more pieces if needed for a stable layer. The second layer may consist of fuel units consisting of no more than two pieces with spacers attached on the bottom and side. The top two layers of the fuel charge must consist of single pieces unless the fuel charge is only three layers. In that instance only the top layer must consist of single units. Three quarter inch (19mm) by 1- $\frac{1}{2}$ inch (38mm) spacers shall be attached to the bottom of piece to maintain a $\frac{3}{4}$ inch (19mm) separation. When a layer consists of two or more units of 4 x 4's and additional $\frac{3}{4}$ inch (19mm) thick by 1.5 inch (38mm) wide spacer shall be attached to the vertical face of each end of one 4 x 4, such that the $\frac{3}{4}$ inch (19mm) space will be maintained when two 4 x 4 units or pieces are loaded side by side. In cases where a layer contains an odd number of 4 x 4's one piece shall not be attached, but shall have spacers attached in a manner that will provide for the $\frac{3}{4}$ inch (19mm) space to be maintained. (See Figure 1). Spacers shall be attached perpendicular to the length of the 4 x 4's such that the edge of the spacer is 1 ± 0.25 inch from the end of the 4 x 4's in the previous layers. Spacers shall be red or white oak and will be attached with either nails (non-galvanized), brads or oak dowels. The use of kiln dried wood is not allowed.

12.2.1 Moisture Content. Determine the test fuel moisture content with a calibrated electrical resistance moisture meter. Determine fuel moisture for each fuel piece by averaging at least three moisture meter readings, one from each of three sides, measured parallel to the wood grain. Measure the moisture content within 2 to 3 inches (50 to 75mm) of each end and at the center of each piece. Average all the readings for each fuel piece in the test fuel charge. Penetration of the moisture meter insulated electrodes shall be 3/4 inch (19 mm). Measure the moisture content within a 4-hour period prior to the test run. The fuel shall be stored under uniform conditions of humidity and temperature ($\pm 10\%$ of nominal RH and ± 5 F of nominal temperature). It is not required to measure the moisture content of the spacers. The addition of moisture to the test fuel is not allowed.

12.2.2 Firebox Volume. Determine the firebox volume in cubic feet. Firebox volume shall include all areas accessible through the fuel loading door where firewood could reasonably be placed up to the horizontal plane defined by the top of the loading door. A drawing of the firebox showing front, side and plan views or an isometric view with interior dimensions shall be provided by the manufacturer and verified by the laboratory. Calculations for firebox volume from computer aided design (CAD) software programs are acceptable and shall be included in the test report if used. If the firebox volume is calculated by the laboratory the firebox drawings and calculations shall be included in the test report.

12.2.3 Test Fuel charge. Test fuel charges shall be determined by multiplying the firebox volume by 10 pounds (4.54 kg) of wood (as used wet weight) per ft^3 (28L). Select the number of pieces of standard fuel that most nearly match this target weight. This is the standard fuel charge for all tests. For example, if the firebox loading area volume is 10 ft^3 (280L) and the firebox depth is 46 inches (1168mm), test fuel charge target is 100 lbs. (45kg) minimum and the piece length is 36

inches (914mm). If 8 - 4 x 4's, 36 inches long weigh 105 lbs (48kg), use 8 pieces for each test fuel charge. All test fuel charges will be of the same configuration.

12.3 Sampling Equipment. Prepare the sampling equipment as defined by ASTM Standard Test Method For Determination Of Particulate Matter Emissions Collected In A Dilution Tunnel.

12.4 Appliance Start-Up. The appliance shall be fired with wood fuel of any species, size and moisture content at the laboratories discretion to bring it up to operating temperature. Operate the appliance until the water is heated to the upper operating control limit and has cycled at least two times. Then remove all unburned fuel, zero the scale and verify the scales accuracy using dead weights.

12.4.1 Pre-Test Burn Cycle. Reload appliance with oak wood and allow it to burn down to the specified coal bed weight. The Pre-Test burn cycle fuel charge weight shall be within $\pm 10\%$ of the test fuel charge weight. Piece size and length shall be selected such that charcoalization is achieved by the time the fuel charge has burned down to the required coal bed weight. Pieces with a maximum thickness of approximately 2 inches have been found to be suitable.

Charcoalization is a general condition of the test fuel bed evidenced by an absence of large pieces of burning wood in the coal bed and the remaining fuel pieces being brittle enough to be broken into smaller charcoal pieces with a metal poker. Manipulations to the fuel bed prior to the start of the test run are to be done to achieve charcoalization while maintaining the desired heat output rate. During the pre-test burn cycle and at least one hour prior to starting the test run, adjust water flow to the heat exchanger to establish the target heat draw for the test. For the first test run the heat draw rate shall be equal to the manufacturer's rated heat output capacity.

12.4.1.1 Allowable Adjustments. Fuel addition or subtractions, and coal bed raking shall be kept to a minimum but are allowed up to 15 minutes prior to the start of the test run. For the purposes

of this method, coal bed raking is the use of a metal tool (poker) to stir coals, break burning fuel into smaller pieces, dislodge fuel pieces from positions of poor combustion, and check for the condition of charcoalization. Record all adjustments to and additions or subtractions of fuel, and any other changes to the appliance operations that occur during pretest ignition period. During the 15-minute period prior to the start of the test run, the wood heater loading door shall not be open more than a total of 1 minute. Coal bed raking is the only adjustment allowed during this period.

12.4.2 Coal Bed Weight. The appliance is to be loaded with the test fuel charge when the coal bed weight is between 10% and 20% of the test fuel charge weight. Coals may be raked as necessary to level the coal bed but may only be raked and stirred once between 15 to 20 minutes prior to the addition of the test fuel charge.

12.5 Test Cycle. Complete a test run in each heat output rate category, as follows:

12.5.1 Test Run Start. Once the appliance is operating normally and the pretest coal bed weight has reached the target value per 12.4.2, tare the scale and load the full test charge into the appliance. Time for loading shall not exceed 5 minutes. The actual weight of the test fuel charge shall be measured and recorded within 30 minutes prior to loading. Start all sampling systems and record all data at intervals of 10 minutes or less. Record water flow and temperature data and monitor the average heat output rate. If the heat output rate gets close to the upper or lower limit of the target range ($\pm 5\%$) adjust the water flow through the heat exchanger to compensate. Make changes as infrequently as possible while maintaining the target heat output rate. The first test run shall be conducted at the category IV heat output rate to validate that the appliance is capable of producing the manufacturer's rated heat output capacity.

12.5.2 Test Fuel Charge Adjustment. It is acceptable to adjust the test fuel charge (i.e. reposition) once during a test run if more than 60 percent of the initial test fuel charge weight has been consumed and more than 10 minutes have elapsed without a measurable (1 lb or 0.5 kg) weight change while the operating control is in the demand mode. The time used to make this adjustment shall be less than 60 seconds.

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

12.5.4 Heat Output Capacity Validation. The first test run must produce a heat output rate that is within 10% of the manufacturer's rated heat output capacity (Category IV). If the appliance is not capable of producing a heat output within this limit, the manufacturer's rated heat output capacity is considered not validated. In such cases, the tests may be continued using the heat output capacity as measured as the Manufacturer's Rated Heat Output Capacity if requested by the manufacturer.

12.5.5 Additional Test Runs. Using the Manufacturer's Rated Heat Output Capacity as a basis, conduct a test for additional heat output categories as specified in 4.4.1. It is not required to run these tests in any particular order.

12.5.6 Alternative Heat Output Rate for Category I. If an appliance cannot be operated in the category I heat output range due to stopped combustion, two test runs shall be conducted at heat output rates within Category II. When this is the case, the weightings for the weighted averages indicated in section 15.1.14 shall be the average of the category I and II weightings and shall be

applied to both category II results. Appliances that are not capable of operation within Category II (<25% of maximum) cannot be evaluated by this test method.

12.5.6.1 Stopped Fuel Combustion. Evidence that an appliance cannot be operated at a category I heat output rate due to stopped fuel combustion shall include documentation of two or more attempts to operate the appliance in burn rate Category I and fuel combustion has stopped prior to complete consumption of the test fuel charge. Stopped fuel combustion is evidenced when an elapsed time of 60 minutes or more has occurred without a measurable (1 lb or 0.5 kg) weight change in the test fuel charge while the appliance operating control is in the demand mode.

Report the evidence and the reasoning used to determine that a test in burn rate Category I cannot be achieved. For example, two unsuccessful attempts to operate at an output rate of 10% of the rated output capacity are not sufficient evidence that burn rate Category I cannot be achieved.

12.5.7 Appliance Overheating. Appliances shall be capable of operating in all heat output categories without overheating to be rated by this test method. Appliance overheating occurs when the rate of heat withdrawal from the appliance is lower than the rate of heat production when the unit control is in the idle mode. This condition results in the water in the appliance continuing to increase in temperature well above the upper limit setting of the operating control. Evidence of overheating includes: 1 hour or more of appliance water temperature increase above the upper temperature set-point of the operating control, exceeding the temperature limit of a safety control device (independent from the operating control), boiling water in a non-pressurized system or activation of a pressure or temperature relief valve in a pressurized system.

12.6 Additional Test Runs. The testing laboratory may conduct more than one test run in each of the heat output categories specified in Section 4.4.1. If more than one test run is conducted at a specified heat output rate, the results from at least two-thirds of the test runs in that heat output rate category shall be used in calculating the weighted average emission rate (see Section 15.1.14).

The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the weighted average emission rate.

13.0 Calculation of Results

13.1 Symbols

E_T – Total particulate emissions measured during a full test cycle – grams

$E_{g/MJ}$ – Emission rate in grams per mega joule of heat output.

$E_{lb/mmBtu\ input}$ – Emissions rate in pounds per million Btu's of heat input.

$E_{lb/mmBtu\ output}$ – Emissions rate in pounds per million Btu's of heat output.

$E_{g/kg}$ – Emissions factor in grams per kilogram of dry fuel burned.

$E_{g/hr}$ – Emission factor in grams per hour.

HHV – Higher Heating Value of fuel = 8550 Btu/lb (19.874 MJ/kg) or as tested per ASTM E711.

LHV – Lower Heating Value of fuel = 7478 Btu/lb (17.382 MJ/kg) or as tested per ASTM E711.

ΔT – Temperature difference between water entering and exiting the heat exchanger.

Q_{out} – Total heat output in BTU's (mega joules).

Q_{in} – Total heat input available in test fuel charge in BTU's (mega joules).

\dot{M} – Mass flow rate of water lb/min (kg/min).

V_i – Volume of water indicated by a totalizing flow meter at the i^{th} reading in gallons (liters).

V_f – Volumetric Flow rate of water in heat exchange system in gallons per minute (liters/min).

t_i – Elapsed time from start of test run at i^{th} reading in minutes.

η – Delivered heating efficiency in percent.

F_i – Weighting factor for heat output category i .

T_{avg} – Average temperature of water in the load side of the heat exchanger.

TI_{avg} – Average temperature of the appliance and water at start of the test.

TF_{avg} – Average temperature of the appliance and water at the end of the test.

MC – Fuel moisture content in percent based on dry fuel weight.

MC_i – Average moisture content of individual 4 x 4 fuel pieces on an dry weight basis.

MC_{sp} – Moisture content of spacers assumed to be 10%.

σ – Density of water in pounds per gallon.

C_p – Specific Heat of Water in Btu per pound degree F.

C_{steel} – Specific Heat of Steel (0.1 Btu/ lb -°F)

W_{fuel} – Fuel charge weight in pounds (kg)

W_i – Weight of individual fuel 4 x 4 pieces in pounds (kg)

W_{sp} – Weight of all spacers used in a fuel load in pounds (kg)

W_{app} – Weight of appliance in pounds

W_{wat} – Weight of water in supply side of the system in pounds

13.2 After the test is completed, determine the particulate emissions E_T

$$E_T = (C_s - C_r) Q_s d\theta$$

13.3 Determine Average Fuel Load Moisture Content

$$MC_{Ave} = \left[\left[\sum W_i \times MC_i \right] + \left[W_{sp} \times MC_{sp} \right] \right] \div W_{fuel}$$

13.4 Determine heat input

$$Q_{in} = (W_{fuel} / (1 + (MC/100))) \times HHV$$

$$Q_{inLHV} = (W_{fuel} / (1 + (MC/100))) \times LHV$$

13.5 Determine heat output and efficiency

13.5.1 Determine heat output as:

$Q_{out} = \sum [C_p \times \Delta T \times \text{Mass Flow Rate}(\text{lb}/\text{min}) \times \text{time interval}(\text{min})] + \text{Change in heat stored in the appliance.}$

$$Q_{out} = \left[\sum (C_p \bullet \Delta T \bullet \dot{M} \bullet t) \right] + (W_{app} \bullet C_{Steel} + C_p W_{water}) \bullet (TF_{avg} - TI_{avg})$$

\dot{M} = Mass flow rate = gal/min x Density of Water (lb/gal) = lb/min

$$\dot{M} = V_f \cdot \sigma$$

$$\sigma = (62.56 + (-.0003413 \times T_{avg}) + (-.00006225 \times T_{avg}^2)) 0.1337 \text{ lbs/gal} :$$

$$C_p = 1.0014 + (-.000003485 \times T_{avg}) \text{ Btu/lb-}^\circ\text{F}$$

$$C_{steel} = 0.1 \text{ Btu/lb-}^\circ\text{F}$$

$$V_f = (V_i - V_{i-1}) / (t_i - t_{i-1}) :$$

Note: V_i is the total water volume at the end of interval i and V_{i-1} is the total water volume at the beginning of the time interval. This calculation is necessary when a totalizing type water meter is used.

Change in heat stored in the appliance = [(weight of the appliance x .1) + (weight of water in the appliance x C_p)] x (final average temperature of the appliance – initial average temperature of the appliance)

Where C_p is the specific heat of water.

13.5.2 Determine Heat output rate as:

$$\text{Heat Output Rate} = Q_{out} / \text{test cycle duration in hours}$$

13.5.3 Determine Emission Rates as:

$$E_{g/MJ} = E_T / (Q_{out} \times 0.001055)$$

$$E_{lb/MM BTU input} = (E_T / 453.59) / (Q_{input} \times 10^{-6})$$

$$E_{lb/MM BTU output} = (E_T / 453.59) / (Q_{output} \times 10^{-6})$$

$$E_{g/hr 10,000 BTU} = E_T / (\text{test duration} \times (Q_{out} / 10,000))$$

$$E_{g/kg} = E_T / (W_{fuel} / (1 + MC/100))$$

$$E_{g/hr} = E_T / \text{test duration}$$

Determine delivered efficiency as:

$$\eta_{del} = (Q_{out} / Q_{in}) \times 100$$

$$\eta_{delLHV} = (Q_{out} / Q_{inLHV}) \times 100$$

13.6 Weighted Average Emissions and Efficiency

13.6.1 Determine the weighted average emission rate and delivered efficiency from the individual tests in the specified heat output categories. The weighting factors (F_i) are derived from an analysis of ASHRAE Bin Data which provides details of normal building heating requirements in terms of percent of design capacity and time in a particular capacity range – or “bin” - over the course of a heating season. The values used in this method represent an average of data from several cities located in the northern United States.

Weighted average delivered efficiency: $\eta_{avg} = \sum \eta_i \times F_i$

Weighted average emissions: $E_{avg} = \sum E_i \times F_i$

13.7 Average BTU/hr for 8 hour burn time and Average 8 hour Efficiency Rating:

13.7.1 Units tested under this standard typically require infrequent fueling, 8 to 12 hours intervals being typical. Rating units based on an Average Output sustainable over an 8 hour duration will assist consumers in appropriately sizing units to match the theoretical heat demand of their application, and the 8 hour efficiency rating will permit consumers to compare the efficiencies of different models.

13.7.2 Calculations:

$$\text{Average BTU/hr for 8 hr. burn time} = X1 + \{(8 - Y1) \times [(X2 - X1) / (Y2 - Y1)]\}$$

Where:

Y1 = Test Duration just above 8 hrs

Y2 = Test Duration just below 8 hrs

X1 = Actual Load for duration Y1

X2 = Actual Load for duration Y2

Average 8 hour Efficiency Rating

$$\text{8 hour Efficiency Rating} = X1 + \{(8-Y1) \times [(X2-X1)/(Y2-Y1)]\}$$

Where:

Y1 = Test Duration just above 8 hrs

Y2 = Test Duration just below 8 hrs

X1 = Actual Efficiency for duration Y1

X2 = Actual Efficiency for duration Y2

13.7.2.1 Determine the Test Durations and Actual Load and Efficiencies for each Category as recorded in Table 1.

13.7.2.2 Determine the data point that has the nearest duration greater than 8 hrs. X1 = Actual Load and Efficiency

Y1 = Test Duration for this data point.

13.7.2.3 Determine the data point that has the nearest duration less than 8 hrs. X2 = Actual Load and Efficiency

Y2 = Test Duration for this data point.

13.7.2.4 Example:

Category	Actual Load (Btu/Hr)	Duration (Hr)	Efficiency (%)
1	15,000	10.2	60
2	26,000	8.4	65
3	50,000	6.4	70
4	100,000	4.7	75

Category 2 Duration is just above 8 hrs, therefore: X1 = 26,000 Btu/hr and Y1 = 8.4 hrs, (For the 8 hour Efficiency calculation; X1 = 65%)

Category 3 Duration is just below 8 hrs, therefore: X2 = 50,000 Btu/hr and Y2 = 6.4 hrs, (For the 8 hour Efficiency calculation; X2 = 70%)

$$\begin{aligned} 8 \text{ Hr Burn Load} &= 26,000 + \{(8-8.4) \times [(50,000 - 26,000)/(6.4-8.4)]\} \\ &= 30,800 \text{ Btu/hr} \\ 8 \text{ Hr Efficiency} &= 65\% + \{(8-8.4) \times [(70\% - 65\%)/(6.4-8.4)]\} \\ &= 66\% \end{aligned}$$

14.0 Report

14.1.1 The report shall include the following.

14.1.2 Name and location of the laboratory conducting the test.

14.1.3 A description of the appliance tested and its condition, date of receipt and dates of tests.

14.1.4 A statement that the test results apply only to the specific appliance tested.

14.1.5 A statement that the test report shall not be reproduced except in full, without the written approval of the laboratory.

14.1.6 A description of the test procedures.

14.1.7 Details of deviations from, additions to or exclusions from the test method, and information on specific test conditions, such as environmental conditions.

14.1.8 A list of participants and observers present for the tests.

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

14.1.10 Drawings and calculations used to determine firebox volume.

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

14.1.12 Temperature, appliance weight, fuel charge weight and water flow data recorded during each test run.

14.1.13 Test run duration for each test.

14.1.14 Calculated results for delivered efficiency at each burn rate and the weighted average Emissions reported as total emissions in grams, pounds per million Btu of delivered heat, grams per mega-joule of delivered heat, grams per kilogram of dry fuel, grams per hour and grams per hour 10,000 Btu. Results shall be reported for each heat output category and the weighted average.

14.1.15 Tables 1 and 2a and 2b must be used for presentation of results in test reports.

14.1.16 A statement of the estimated uncertainty of measurement of the emissions and efficiency test results.

14.1.17 Raw data, calibration records, and other relevant documentation shall be retained by the laboratory for a minimum of 7 years.

Table 1.

CAT	Load % Capacity	Tgt Load Btu/hr	Act Load Btu/hr	Test Duration Hours	Wood Wt Lb	Q_{in}	Q_{out}	η_N	E_T	E	E	E	E	E
						Btu	Btu	%	g	g/MJ	lb/mmbtu	g/hr	g/kg	g/hr 10,000 Btu
I	<15% of max													
II	16 – 24% of max													
III	25 - 50% of max													
IV	Max capacity													

Average Btu/hr for 8 hr. burn time

Table 2a Heating Season Weighting.

CAT	Weighting Factor (F_i)	$E_{g/MJ,i} \times F_i$	$E_{g/kg,i} \times F_i$	$E_{lb/mmbtu} \times F_i$	$E_{g/hr} \times F_i$	$E_{g/hr 10,000 Btu} \times F_i$
I	0.175					
II	0.275					
III	0.450					
IV	0.100					
Totals	1.000					

Table 2b Year Round Use Weighting.

CAT	Weighting Factor (F _i)	E _g /MJ _i x F _i	E _g /kg _i x F _i	E _{lb} /mmbtu x F _i	E _g /hr x F _i	E _g /hr 10,000 Btu x F _i
I	0.437					
II	0.238					
III	0.275					
IV	0.050					
Totals	1.000					

15.0 Precision and Bias

15.1 Precision—It is not possible to specify the precision of the procedure in Draft Test because the appliance operation and fueling protocols and the appliances themselves produce variable amounts of emissions and cannot be used to determine reproducibility or repeatability of this measurement method.

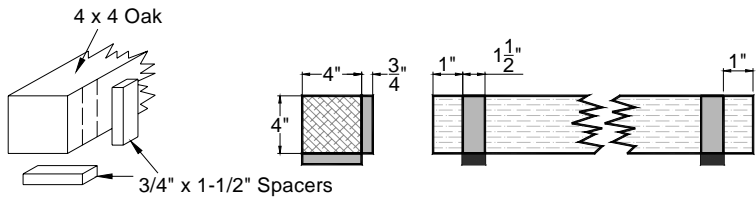
15.2 Bias—No definitive information can be presented on the bias of the procedure in Draft Test Method 28 OWHH for measuring solid fuel burning outdoor hydronic heater emissions because no material having an accepted reference value is available.

16.0 Keywords

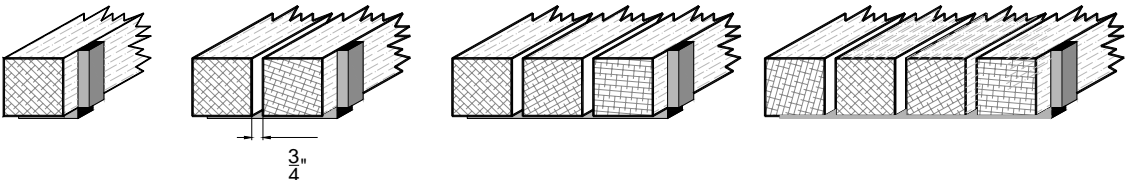
16.1 Solid fuel, hydronic heating appliances, wood-burning, outdoor hydronic heaters.

Figure 1. Typical Test Fuel Piece

Test Fuel Spacer Configuration



Test Fuel Units (1, 2, 3 and 4 pieces)



Typical Test Fuel Charge Configurations

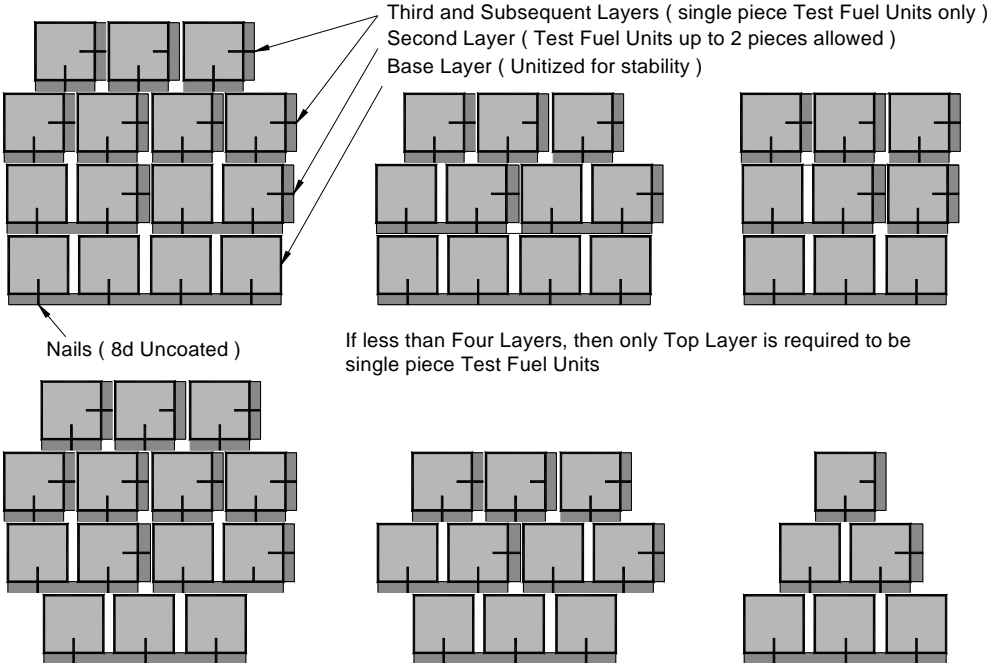


Figure 2. Heat Exchanger Schematic

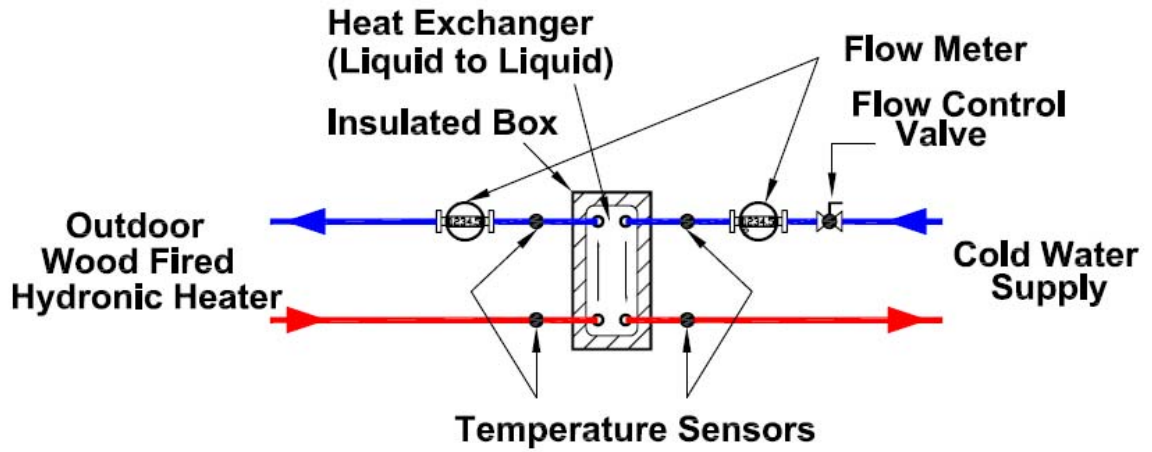
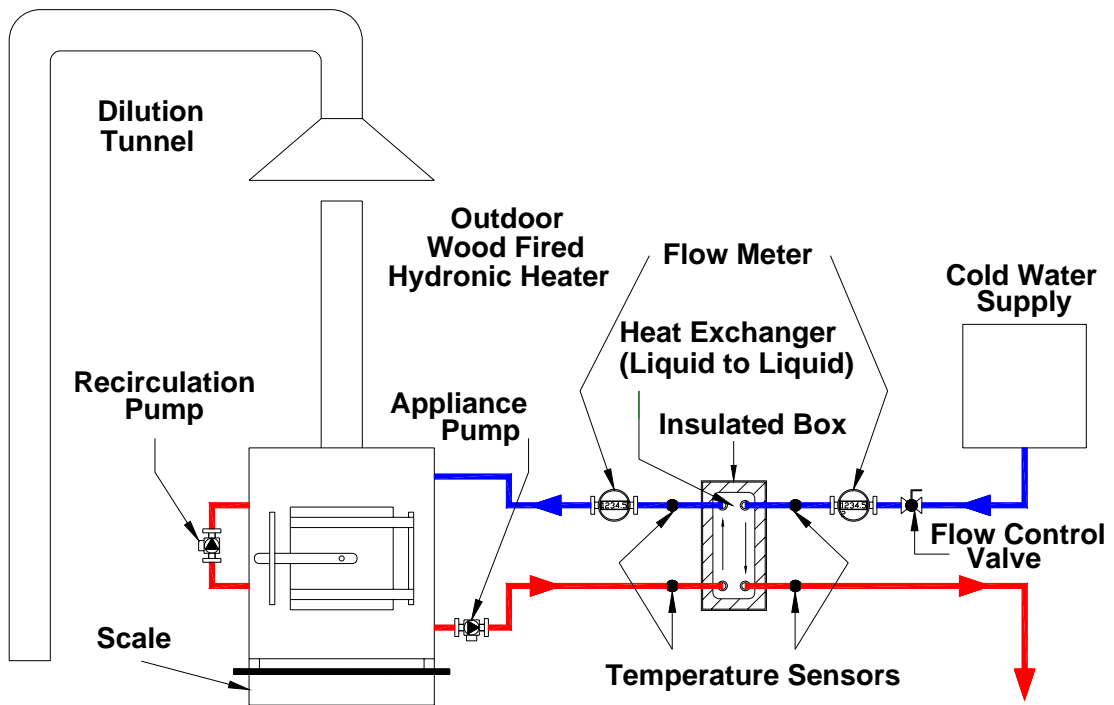


Figure 3. Set-Up Schematic



Note: Illustrated appliance pump location and flow path through the appliance are generic and may vary based on the unit being tested.