Integrated Duty Cycle (IDC) Test Method for Certification of Thermostatically Controlled Automatic-Feed Hydronic Heating Appliances with External Thermal Storage: Measurement of Particulate Matter (PM), Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Appliances (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 28 WHH – Measurement of Particulate Emissions and Heating Efficiency of Wood-Fired Hydronic Heating Appliances

1. Scope and Application

1.1. This test method applies to automatic feed, wood-fired hydronic heating appliances that utilizes an external buffer tank(s) (sometimes called thermal storage) as integral to the appliance operation. The units typically transfer heat through the circulation of a liquid heat exchange media such as water or a water-antifreeze mixture. Throughout this document, the term “water” will be used to denote any of the heat transfer liquids approved for use by the manufacturer.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide, and delivered heating efficiency at specified heat loads based on the appliances rated heat capacity.

1.3. Particulate emissions are measured by the dilution tunnel method as specified in ASTM E2515 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* using only Emfab Pallflex filters. Additional particulate matter emissions measurements may also use the Tapered Element Oscillating Microbalance (TEOM) continuous PM method, as detailed in this test method.

1.4. Steady Heat Load efficiency, which is reflective of efficiency measurements in current EPA Federal reference methods is determined by calculating the delivered efficiency at the high and low load steady heat load periods of the test run (Phase 2 and 3). Delivered annual fuel use efficiency is determined by measurement of the usable heat output (determined through measurement of the flow rate and temperature change of water circulated through a heat exchanger external to the appliance) and the heat input (determined from the mass of dry fuel burned and its higher heating value) over the entire test run. Changes in the temperature of the appliance and thermal storage system from the start to the end of the run are considered in the heat output determination. Delivered efficiency does not attempt to account for energy loss in the piping between the system and the building heat distribution system. Energy loss from the connected piping and buffer tank to the surrounding test lab are included in the efficiency determination.

1.5. Products covered by this test method include both pressurized and non-pressurized hydronic heating appliances intended to be fired with wood and for which the manufacturer specifies for indoor or outdoor installation. The system is commonly connected to a heat exchanger by insulated pipes and normally includes a pump to circulate heated liquid. These systems are used to heat structures such as homes, barns, schools, and greenhouses. They also provide heat for domestic hot water, spas, and swimming pools.

1.6. Distinguishing features of products covered by this standard include:

1.6.1. The manufacturer specifies installation either inside a building or outside.

1.6.2. Products that automatically feed fuels, such as pelletized wood or wood chips.

1.6.3. An aquastat or similar device that controls the feed rate and combustion air supply to maintain the liquid in the appliance within a predetermined temperature range.

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

1.7. 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.

1.8. Analyte. Particulate matter (PM). No CAS number assigned. Carbon monoxide (CO). No CAS number assigned.

1.9. Data Quality Objectives.

1.9.1. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.9.2. Measurement of emissions and 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.

1.9.3. This is a laboratory method intended to capture operating periods that are representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. CAN/CSA-B415.1: Performance Testing of Solid-Fuel-Burning or latest approved EPA version.

2.2. ASTM E2515: Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel or latest approved EPA version.

2.3. NESCAUM Standard Operating Practices for Thermo 1405 TEOM

2.4. NIST Monograph 175, Standard Limits of Error

3. *Definitions*

3.1. Aquastat – A control device that opens or closes a circuit to control the status of the burner in response to the temperature of the heating media in the heating appliance.

3.2. Appliance – a woodburning hydronic heater capable of and intended for central heating or domestic water heating, as defined in the applicable regulation. Appliance includes combustion chamber, fuel hopper size sufficient for testing, operating controls, and recirculation loop, if specified, and any other accessory required for standard operation, such as a barometric damper, an aquastat, pump, etc.

3.3. Buffer - storage tank or tanks including pressure relief valve and internal temperature measurement points required for operation of the system as specified in the manufacturer's instructions shipped with the hydronic heater. The size of the buffer shall be the minimum specified in the manufacturer's instructions shipped with the hydronic heater.

3.4. Catch - any mass from the sample probe system including PM on the front filter, back filter, and front half sample probe.

3.5. Cooling Water - cold water from an external source ("city water") used to extract the heat load.

3.6. Cycle – A cycle includes a shutdown initiated by a charged buffer tank and a startup initiated by a call for heat from the appliance to restart of the burner due to depletion of energy in the buffer tank.

3.7. Delivered Efficiency – The percentage of heat available in the fuel burned that the system delivers to a simulated heating load as specified in this test method.

3.8. Emission Factor – the emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance.

3.9. Emission index – the emission of a pollutant expressed in mass per unit mass of fuel used.

3.10. Emission Rate – the emission of a pollutant expressed in mass per unit time.

3.11. Failed Test Run – any complete or partial test that does not meet the specifications detailed in this test method at the fault of the system operation or does not meet the emission standard at the fault of the system operation.

3.12. Firebox - the chamber in the appliance in which the test fuel charge is fed into and combusted.

3.13. Heat Load: Rate of transfer of heat from the system to the cooling water through the cooling heat exchanger, Btu/hr (MJ/hr)

3.14. Heat Output rate, Total – Rate of total energy including the change in energy of the appliance, change in energy of the buffer tank or tanks and the sum of the energy transfer from the system to the cooling water through the cooling heat exchanger (MJ/hr).

3.15. Hydronic Heater– Same as appliance.

3.16. Idle – A control state where the hydronic heater is not feeding into the firebox chamber, the burner is inactive, and there is "no call for heat". This includes the hydronic heater's transition to idle, which may include purging of the feed tube or auger and burnout of remaining fuel in the firebox chamber. Idle ends when there is an active call for heat and signals the hydronic heater to activate burner. This may be visually indicated by a LED signal, an alert, or change in control status on the hydronic heater.

3.17. Manufacturer's Rated Heat Output Capacity −The value in Btu/hr (MJ/hr) that the manufacturer specifies that a particular model of an appliance and buffer is capable of supplying in steady state at its design capacity as verified by testing during Phase 1 and Phase 6 of the test protocol.

3.18. On-cycle – the burner is activated and fuel is being fed to the combustion chamber. This includes the cycling on period of restarting the burner and any control sequences related to igniting the fuel.

3.19. Off-cycle – the appliance cycles off and burner is not active and fuel is no longer fed into combustion chamber, but may include purging of feed tube or auger during initial shutdown

3.20. Phase – A distinct period in the test run with its own operational procedures and conditions.

3.21. Phase X Delivered Efficiency – The delivered efficiency of individual phases (X), specifically for Phase 2, Phase 3, and Phase 6 per test run.

3.22. Phase X Delivered Efficiency Average – Average delivered efficiency of individual phases (X) per test series specifically Phase 2, Phase 3, and Phase 6

3.23. NIST – National Institute of Standards and Technology

3.24. Series Delivered Efficiency – The overall average delivered efficiency of each valid test run completed.

3.25. System - combination of the appliance and buffer and required interconnections and controls.

3.26. Temperature, Average Hydronic Heater - simple average of the hydronic heater supply and the return Water entering the hydronic heater.

3.27. Temperature, Average Buffer- average of all six of the test temperature sensors internal to the tank. If more than one buffer tank is required, then average all sensors. This does not include temperature sensors which may be added by the manufacturer for control purposes.

3.28. Temperature, Return water entering the hydronic heater - temperature of the water downstream of the mixing valve, as it enters the return connection on the hydronic heater.

3.29. Temperature, Hydronic Heater Minimum Operating - the lowest temperature of the return water entering the hydronic heater as specified in the manufacturer's instructions shipped with the system. The minimum operating temperature shall be 140 ˚F (60 ˚C) or higher if specified by the manufacture for all phases except Phase 1.

3.30. Temperature, Hydronic Heater Modulation - on rising hydronic heater temperature, the temperature measured at the control sensor point at which the control acts to reduce the burner input from the full fire level.

3.31. Temperature, Hydronic Heater Operating Limit - on rising hydronic heater temperature, the temperature at the control sensor point at which the control initiates a shutdown of the burner.

3.32. Temperature, Hydronic Heater Setpoint – The temperature the hydronic heater aims to maintain while operating at maximum burn rate.

3.33. Temperature, System Operating Limit - on rising buffer temperature, the temperature at the control sensor point or points at which the control initiates a shutdown of the burner. This typically will be below the hydronic heater operating limit temperature.

3.34. Temperature, System Restart - on falling buffer temperature, the tank temperature at the control sensor point at which the control initiates a restart of the burner.

3.35. Temperature, Safety High Limit - on rising appliance temperature, the hydronic heater temperature at the control sensor point at which the control forces a burner shut down and requires a manual restart.

3.36. Temperature Range, Hydronic Heater Modulation - temperature range between the hydronic heater setpoint temperature and the operating limit.

3.37. Temperature Range, System - the temperature range between the system restart and the system operating limit.

3.38. Test Data– means the data for all test runs conducted on the system, including any data collected during failed and invalid runs and includes records of preparation of standards, identification of equipment used and personnel present, records of calibrations, raw data sheets for field sampling, raw data sheets for field and laboratory analyses, chain-of-custody documentation, and example calculations for reported results.

3.39. Test Series– means the data for all test runs conducted on the system.

3.40. Test Facility - the area in which the heating system is installed, operated, and sampled for emissions.

3.41. Test Run - An individual emission test, which encompasses the time required to complete all specified phases of the test profile.

3.42. Test Tun Delivered Efficiency –The delivered efficiency of a test run.

3.43. Thermopile - A device consisting of a number of thermocouples connected in series, used for measuring temperature differential.

3.44. Valid Test Run – a complete test run that complies with all requirements detailed in this test method. A failed completed test run that does not meet emission standards may still be considered a valid test run if all requirements detailed in the method are met.

4. Summary of Test Method

4.1. Dilution Tunnel. Emissions are determined using the "dilution tunnel" method specified in ASTM E2515-11 *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 equilibrated and weighed before and after each 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. The method also includes optional use of a real-time particulate matter measurement that allows for providing one-minute data, which can be used to provide one hour and test phase emissions information.

4.2. Particulate Matter. PM emissions are determined using a dilution tunnel method specified in ASTM 2515-11 *Standard Test Method for Determination of Particulate matter Emissions Collected in a Dilution Tunnel* with exceptions as defined in Section 9.1. The flow rate in the dilution tunnel is maintained at a constant rate throughout the test cycle and accurately measured. Three different particulate sampling methods are used in this test method.

4.2.1. Filter-based method. Samples of the dilution tunnel flow stream are extracted at a constant flow rate and drawn through high-efficiency filters as defined in ASTM E2515-11 using Teflon coated filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency. The filters are equilibrated and weighed before and after the test to determine the emissions collected 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.

4.2.2. Real-time PM Measurements (Optional). The second method is a real-time particulate measurement method based on a Tapered Element Oscillating Microbalance (TEOM) instrument, Thermo model 1405 TEOM or its equivalent, operated using the specifications detailed in the document titled, "*NESCAUM Standard Operating Procedures for Using TEOM 1405 in a Dilution Tunnel"* available at: https://www.nescaum.org/topics/test-methods.

4.3. Carbon Monoxide. The CO measured in the dilution tunnel and used to calculate efficiency determination.

4.4. Delivered Efficiency. Efficiency is measured by determining the fuel energy input and appliance output.

4.5. Operation. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature and ends with the appliance in fully heated state. The second and third test runs are started a slightly warmer temperature. The appliance is operated at a variety of heat load loads representing start-up emissions, high heat load, low heat load, cycling, idling, and recovery from nighttime set back. The appliance is operated through six heating phases during the test run. To complete the certification test, a minimum of three full test runs are averaged to determine the test results. For automatic feed systems, fuel is fed as determined by appliance delivery systems.

4.6. Repeatability. A series of at least three test runs comprised of six different heat loads or phases are conducted for certification or audit purposes

5. *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 manufacturers' 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.

6. ***Test Equipment and Supplies***. The following items are required for sample collection:

6.1. Anemometer. A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min), for measuring air velocities near the test appliance.

6.2. Appliance Flue.

6.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer.

6.2.2. Other chimney types (e.g., solid pack insulated pipe) may be used in place of the steel flue pipe if the appliance manufacturer's written appliance specifications require such chimney for home installation. Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

6.3. Appliance Side Water Flow Meter (optional). A water flow meter with an accuracy of ± 1% of the flow rate is recommended to monitor the supply-side water flow rate.

6.4. Barometer. Aneroid or other barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.5 mm Hg).

6.5. B*uffer Temperature Sensors*. To determine the average temperature of the buffer, in real time, six temperature sensors shall be located internally per buffer tank. The tank volume shall be divided into six equal volumes and a sensor shall be located at the vertical center of each volume. The sensors shall be located as close to the vertical centerline of the tank as practical and not be in contact with tank walls or any internal obstruction such as piping or internal heating coils. It may be necessary to modify top connections on the tank to enable the insertion of a 6-point probe for this purpose. The sensors shall not be attached to the surface of the tank.

6.6. Dilution Tunnel must meet the requirements of ASTM E2515, clauses 6.1.6 and 9.2.

6.7. Dilution Tunnel temperature and relative humidity measurement. A probe capable of measuring tunnel temperature to within 0.9 ˚F (0.5 ˚C)) and tunnel RH to within 2%, such as the Omega HX85-A or equivalent.

6.8. Flue Gas Temperature Measurement. Must meet the requirements of CSA B415.1-2010, Clause 6.2.2.

6.9. Flue Gas Composition Measurement. Must meet the requirements of CSA B415.1-2010, Clauses 6.3.1 through 6.3.3.

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

6.11.Humidity Gauge. Psychrometer or hygrometer for measuring Relative humidity measurement in lab with accuracy of 2% RH between 5 and 95% RH.

6.12.Insulated Solid Pack Chimney. For installation of appliances. Solid pack insulated chimneys shall have a minimum of 2.5 cm (1 in.) solid-pack insulating material surrounding the entire flue and possess a label demonstrating conformance to U.L. 103 (incorporated by reference—see §60.17).

*6.13.*Ionizing air blower (or 210Polonium alpha sources). For reducing static charge build up on beakers and/or filter media.

6.14. Platform Scale and Monitor. 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 pound (± 0.45 kg) and a readout resolution of ± 0.2 pound (± 0.1 kg).

6.15. Test Facility Temperature Monitor. A thermistor, RTD, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1˚F of expected temperatures.

6.16. Water Temperature Difference Measurement. A Type –T 'special limits' thermopile with a minimum of 5 pairs of junctions shall be used to measure the temperature difference in cooling water entering and leaving the heat exchanger. The temperature difference measurement uncertainty of this type of thermopile is equal to or less than ± 1.0 ºF (± 0.5 ºC). Other temperature measurement methods may be used if the temperature difference measurement uncertainty is equal to or less than ± 1.0 ºF (± 0.50 ºC). This measurement uncertainty shall include the temperature sensor, sensor well arrangement, piping arrangements, lead wire, and measurement / recording system. The response time of the temperature measurement system shall be less than half of the time interval at which temperature measurements are recorded.

6.17. Water Flow Meter. A water flow meter shall be installed in the inlet to the load side of the heat exchanger. The flow meter shall have an accuracy of ± 1% of the measured flow.

6.18. Water Temperature Measurement. Thermocouples or other temperature sensors to measure the water temperature at the inlet and outlet of the load side of the heat exchanger must meet the calibration requirements specified in Section 8 of this method.

7. Safety

7.1. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to performing this test method.

7.2. These tests involve combustion of wood, which releases substantial amounts of heat and combustion products. 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. Exposure of personnel to unsafe levels of carbon monoxide must be avoided, and the use of continuous ambient carbon monoxide monitoring is strongly recommended.

8. Calibration, Standardization and Quality Control

8.1. ASTM E2515-11. Perform all calibrations required by ASTM E2515-11

8.2. Water Temperature Sensors. Temperature measuring equipment shall be calibrated before initial use and at least semi-annually thereafter. Calibrations shall follow NIST Monograph 175, Standard Limits of Error.

8.3. Heat Exchanger Load Side Water Flow Meter. The heat exchanger load side water flow meter shall be calibrated within the flow range used for the test run using NIST-traceable methods.

8.4. Scales. Perform a multipoint calibration using NIST-traceable methods (at least five points spanning the operational range) of the platform scale before its initial use and semiannually, thereafter. Calibration results from an accredited laboratory are sufficient for this purpose. Before each certification test, audit the scale with the appliance in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected change in fuel mass during a run. If the scale cannot reproduce the value of the calibration weight within 0.09 kg (0.2 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, then recalibrate or service scale.

8.5. Anemometer. Calibrate the anemometer as specified by the manufacturer's instructions before the first certification test and semiannually thereafter.

8.6. Humidity Gauge. Calibrate as per the manufacturer's instructions before the first certification test and semiannually thereafter

8.7. Flue Gas Analyzers. In accordance with CSA B415.1-2010, Clause 6.8.

9. Sampling, Test Specimens, and Test Appliances

9.1. Modifications to ASTM 2515 requirements.

9.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample.

9.1.2. Dilution tunnel temperature and relative humidity shall be measured and logged near the sample probe to calculate tunnel dewpoint.

9.1.3. Filter temperature shall be measured and logged using a measurement method with an accuracy of 1 ˚F (0.5 ˚C)) or better.

9.1.4. For a valid test run the following conditions shall not exceed any of the following conditions for a period of more than five minutes in total:

9.1.4.1. Filter temperature shall remain between 80 and 90 ˚F (26.7 to 32.2 ˚C)

9.1.4.2. The dilution tunnel should be adjusted to a flow rate that is high enough for the dilution tunnel temperature, at the particulate measurement point, to be no more than 110 ˚F (43.3 ˚C) for any rolling 10-minute average.

9.1.4.3. Tunnel relative humidity shall not exceed 95%.

9.1.4.4. Tunnel dew point temperature shall be at least 3.6 ˚F (2 ˚C) less than filter temperature.

9.1.4.5. If any parameter is exceeded, the test report should explicitly report results from the run and note where exceedances occurred. The test run shall be invalid unless supporting evidence proves any exceedances do not affect test results and has been approved by regulating authorities.

9.1.5. Particulate Matter Sampling for one-hour filter pull. PM emissions allow the use of two options to obtain integrated results and one-hour emissions data.

9.1.5.1. **Option 1** - three ASTM E2515 trains will be used for this testing.

9.1.5.2. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases.

9.1.5.3. Train 1: Start-up Measurement. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

9.1.5.4. ASTM E2515 Trains 2 and 3: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

9.1.5.5. Option 1 use three ASTM E2515 trains, two are run through the entirety of the test and one obtains measurement for startup and the first hour of Phase 2.

9.1.6. **Option 2** – 2 ASTM E2515 trains and TEOM.

9.1.6.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases individually and for each run.

9.1.6.2. ASTM E2515 Trains 1 and 2: Integrated load measurement. Two, dual ASTM E2515 trains will measure particulate for the entire test run.

9.1.6.3. TEOM data will be collected at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in the TEOM SOP found at https://www.nescaum.org/topics/test-methods. TEOM data shall be recorded on an excel spreadsheet following the minimum data reporting requirements. Emissions from the ASTM E2515 trains shall serve as the primary PM emission measurement. The TEOM data will be used to report emissions for the first, one-hour period.

9.1.7. **Option 3** - two ASTM E2515 trains will be used for this testing.

9.1.7.1. Proportional Rate Variation shall meet the requirements of ASTM E2515 for all phases individually and for each run.

9.1.7.2. A measurement of the start-up phase will be reported using one ASTM E2515 train. This measurement will commence at the beginning of the test and ends sixty (60) minutes after commencing the test.

9.1.7.3. Start-up Measurement (one-hour filter pull) – Both trains will change filters at the one hour. Data from this filter pull will be reported separately as the one-hour measurement. PM from one-hour filters will be combined with other filter measurements for total filter run.

9.1.8. Weigh room conditions. The following conditions shall be met:

9.1.8.1. The facility shall use an active ionizing air blower (or 210Polonium alpha sources) to neutralize charge associated with the filter. 210Polonium alpha sources must be replaced annually or more often.

9.1.8.2. Temperature range of 68 to 78 ˚F (20 to 25.6 ˚C).

9.1.8.3. Relative humidity shall be no higher than 45%.

9.1.8.4. *Filter equilibration / conditioning post sample collection*. Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used. PREPARATION OF SALT SOLUTIONS: Use only pure distilled water to make up the solution. Put 200 g of the salt into a beaker. Gradually add distilled water. Stir well after each addition, until the salt can absorb no more water, as will be evidenced by some free liquid on the surface of the mixture. For best results keep the excess liquid to a minimum. The mixture should be slushy but must have a small amount of liquid water on the surface. Put this slushy mixture in the desiccant tray of the equilibration chamber. After equilibration, the chamber RH should measure 33% +/- 3%.

9.1.9. Filter weight measurements. Report the following filter measurements:

9.1.9.1. Day zero – initial filter measurement before going into the equilibrium chamber.

9.1.9.2. Final filter measurement or day seven measurement, whichever measurement comes first.

9.1.9.3. *Blanks*. Test reports shall measure and report data on blanks as follows:

9.1.9.4. Lab blank, which is removed from each filter batch, stored in a protective environment, and weighed during each weighing session.

9.1.9.5. Room blank collected during every test run. The blank shall be placed within 10 feet of the intake for the dilution air

9.1.10. Probe Catch: Report sampling system catch as a separate number from back filter catch.

9.2. Test Specimens. Systems (appliance and buffer tank) shall be supplied as complete systems, including all controls and accessories necessary for installation at the test facility including thermal buffer tank description and volume. A full set of specifications, designs, and assembly drawings shall be provided when the product is placed under certification of a third-party agency. The manufacturer shall provide a tank with the minimum volume needed for operation and any parts that are specific for operation. Examples of parts to be supplied by the manufacturer would be a thermostat or various sensors required for communicating buffer tank temperature to the appliance, recirculation loops (if needed), specific pump (if needed), all fittings for coming off the buffer tank, etc.

9.3. User Guide. The manufacturer must supply a one-page user guide that will direct certain portions of the test protocol. The User Guide must be provided to the lab and the consumer as a single sheet and documented in the test report. The user guide shall be the only directions provided and used by the testing facility for certification purposes; it shall address key user operations for simple baseboard heating, and it shall conform to the following requirements. Manufacturers are not allowed to direct or inform any portion of testing or deviate from operations specified in the User Guide, as the User Guide is the only information that can be used to inform appliance operation during certification testing. User Guide Layout Requirements – the User Guide shall conform to the following design specifications:

9.3.1. Directions must be illustrated by text and colored pictures

9.3.1.1. Font size – minimum font size is 12.

9.3.1.2. Use of columns allowed

9.3.1.3. Margins – must have a minimum of ¾” inch margins

9.3.1.4. A minimum of 40% of the user guide must use graphics or photos to support text directions.

9.3.1.5. Complete instructions but fit on a double sided of an 8 x11.5-inch sheet of paper

9.3.1.5.1. One side may be used to show tank setup and control settings

9.3.1.6. Must be provided in a laminated form to the consumer.

9.3.2. User Guide elements – The User Guide cannot contradict or deviate from user instructions provided in the appliance user manual. The User Guide shall include information on the following items.

9.3.2.1. Appliance preparation – what must be done to the appliance prior to starting a fire to include appliance setpoints and software settings. Settings must reflect use in high-temperature heating systems.

9.3.2.2. Appliance and buffer (system) settings – to include modulation, setpoint, and restart, operating limits, and safety high limit temperatures, and other operations that are part of normal operation (cleaning cycles, etc).

9.3.2.3. Fuel properties – what types of fuel and fuel moisture requirements are allowed for use in the appliance. The fuel properties detailed in the User Guide are for homeowner use, for certification testing, fuel requirements shall follow the protocols detailed in this method.

9.3.2.4. Start-up procedures – general guidelines for properly starting the appliance to include starting procedures and appliance settings to include software configurations.

9.3.2.5. Reloading procedures – If applicable, guidelines for properly reloading fuel once a fire has been started in the appliance.

9.4. Preparation of Apparatus

9.4.1. Place the appliance centrally on the platform scale meeting the requirements

9.4.2. Setup shall conform to the schematics provided below.

9.4.2.1. Manufacturer may assist or instruct during install prior to the first test.

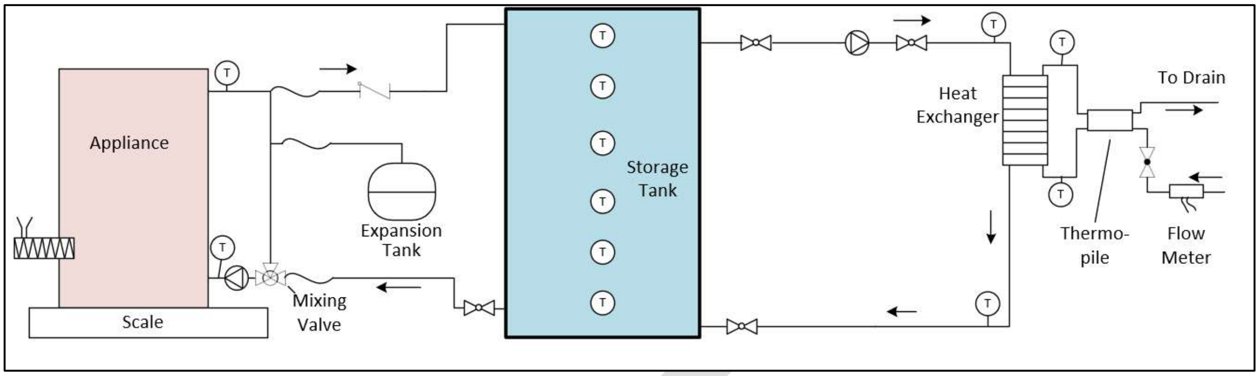

Figure 1. *Test Plumbing with 1 buffer*

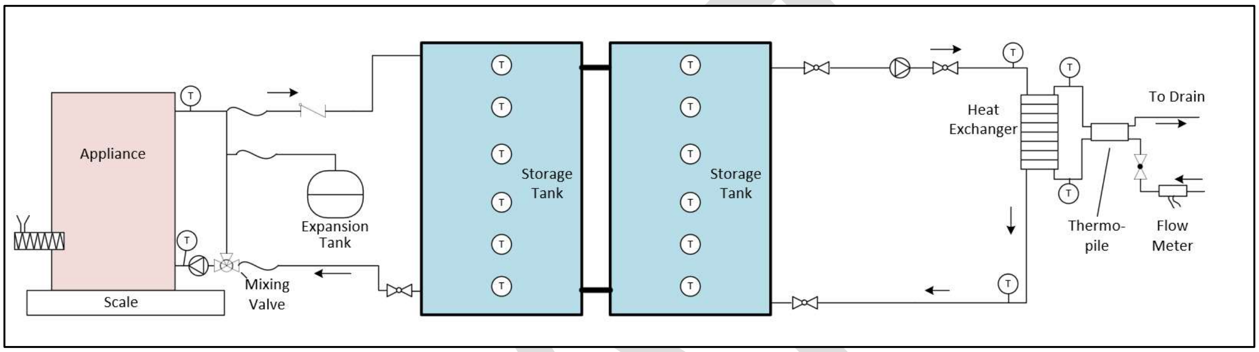

Figure 2 Test plumbing with multiple buffers

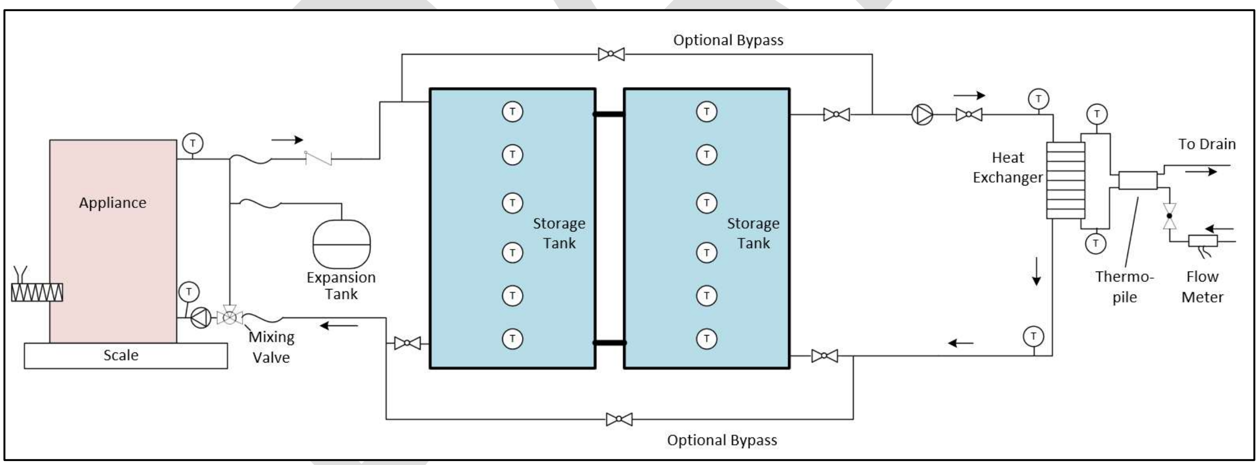

Figure 3 Optional buffer bypass loop for safety

9.4.3. A recirculation pump may be installed between connections at the top and bottom of the appliance to minimize thermal stratification if specified by the manufacturer's instructions shipped with the unit. If specified by the manufacturer, the manufacturer shall provide all piping, pumps, and controls necessary for the recirculation system. 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.

9.4.4. If the manufacturer's instructions shipped with the unit specify that a thermal control valve or other device be installed and set to control the return water temperature to a specific set point, the valve or other device shall be installed and set per the manufacturer's written instructions to reflect a high-temperature installation, unless the manufacturer specifies that the appliance is for use only in low-temperature installations.

Starting Weight. Prior to filling the appliance with water, weigh and record the appliance mass.

9.4.5.Heat Exchanger

9.4.5.1. Plumb the system 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.

9.4.5.2. Locate temperature sensors to measure the water temperature at the inlet and outlet of the supply side of the heat exchanger.

9.4.5.3. Install a thermopile (or equivalent instrumentation) meeting the requirements of Section 6.16 to measure the water temperature difference between the inlet and outlet of the load side of the heat exchanger.

9.4.5.4.Place the heat exchanger in a box with 2 in. (50 mm) of expanded polystyrene (EPS) foam insulation surrounding it to minimize heat losses from the heat exchanger.

9.4.5.5. The reported heat load output rate shall be based on measurements made on the load side of the heat exchanger.

9.4.6. Install a calibrated water flow meter in the heat exchanger load side cold water line. 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 temperature at which it is calibrated.

*9.4.7.*Temperature instrumentation shall be installed in the appliance outlet and return lines and appliance recirculation loop (if needed). The average of the outlet and return water temperature on the supply side of the system shall be considered the average appliance temperature. Installation of a water flow meter in the supply side of the system is optional.

9.4.8. 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. Conditioning

10.1. Appliance Aging. Prior to testing, the appliance shall be operated for a minimum of 50 hours using a variety of heat loads. The conditioning may take place at the manufacturer's facility prior to testing or at the certification facility.

10.1.1. If the appliance uses a catalytic combustor, it must be engaged according to manufacturer's instructions and operate for at least 50 hours during the break-in period. Report hourly catalyst exit temperature data and the hours of operation.

10.2. *Appliance Aging Documentation.* The aging procedure shall be conducted and documented by the manufacturer or the certified testing laboratory. All aging data must be reported and shall include the hours of operation and heat loads for aging, hourly flue gas temperature, amount of fuel burned, fuel parameters (species, heat loads, and fuel types), air and control settings used, and note the time spent in each air setting phase.

11. Procedure

11.1. Test Facility Conditions. The test facility shall meet the following requirements during testing:

11.1.1. Shall conform to 9.7 of ASTM E2515-11

11.1.2. The test facility temperature shall be maintained between 65 and 90˚F (18 and 32 ˚C) during each test run

11.1.3. Air velocities within 2 ft(0.6 m) of the test appliance and exhaust system shall be less than 50 ft/min (0.25 m/sec) without fire in the unit.

11.1.4. For test facilities with artificially induced barometric pressures (e.g., pressurized chambers), the barometric pressure in the test facility shall not exceed 30.5 in. Hg (775 mm Hg) during any test run and shall be recorded before and after the test run.

11.2. Test Fuel. This method can be used with wood pellet fuels and fuel chips.

11.2.1. Pelletized fuels shall conform to the following requirements:

11.2.1.1. Fuel used must be PFI, CANplus, or ENPlus certified, or other equivalent fuel certification standard.

11.2.1.2. Test fuel must undergo and report ultimate/proximate analysis by an independent accredited lab.

11.2.1.3. All fuels used for testing must have a temperature no greater than 5 ˚F of laboratory temperature when loaded into the appliance within 60 minutes of starting the test.

11.2.2. Wood chip fuels shall conform to the following requirements:

11.2.2.1. Fuel used for testing must undergo ultimate/proximate analysis by an independent accredited lab.

11.2.2.2. Fuel used for testing must be characterized by ANSI/ASABE AD17225-4:2014 FEB2018 Solid biofuels — Fuel specifications and classes — Part 4: Graded wood chips

11.3. Manufacturer participation in certification testing

11.3.1. A representative of the manufacturer may observe testing but may not provide instructions to the certification lab, in any form, with testing staff or equipment once the certification tests begin. The names of testing witnesses cannot be withheld as confidential business information (CBI).

11.3.2. During certification testing, the appliance cannot be connected for remote access. Nor can the appliance be operated remotely. For example, the appliance cannot be connected to the internet unless remote access is to allow for remote witnessing or recording of the test. Remote access may only be granted by the certification laboratory. If remote access is granted, witness list shall reflect those who have been granted remote witness capacity and provide recordings of remote activities as part of the test report.

11.4. Appliance Instructions and Program Configuration/Setting

11.4.1. For certification testing, all system control settings shall be tested with all controls and software set as-the manufacturer will ship or install, often referred to as default settings. These default settings shall be specified by the manufacturer and included in the test report. Settings for certification testing shall match those communicated in all manufacturer materials and installation instructions to the installer or end-user.

11.4.2. Appliance Operation and Adjustments. If appliance does not arrive with control settings preset, then follow user guide instructions for control setting. Adjustments to controls are not allowed once testing has begun. If adjustments to controls are required due to invalid test run, then it is documented, and the user guide must be revised prior to starting the new test series.

11.4.3. Manufacture representative may assist with control settings prior to the start of the test, but must be consistent with the user guide and any deviations from the User Guide will require a revised User Guide prior to the start of the certification test series.

11.4.4. Control settings and the documentation of the control settings shall be included in the user guide and in the non-CBI portion of the test report.

11.5. Before each test series, the firebox shall be vacuumed. Testing shall begin without any ash or other materials in the appliance. Record fuel weight data and appliance temperature measurements at 1-minute intervals.

11.6. Before initiating the compliance test, clean the flue and dilution tunnel with an appropriately sized wire chimney brush before each certification test. Test documentation should include the date and time of flue cleaning.

11.7. The flow rate of water between the buffer and the load heat exchanger shall be set to achieve a return temperature from the heat exchanger back to the system of 140˚F (60 ˚C) or greater.

11.8. *Low Appliance Temperature*. If at any time, average water temperature falls below the appliance minimum operating temperature, as specified by the User Guide, then cooling will be stopped until the appliance water temperature average reaches the target temperature. All interruptions in heat load will be documented and reported.

11.9. All water temperatures, water flowrates, and appliance temperatures, and all other temperature sensors shall be recorded at intervals of 1 minute or less.

11.10. The hydronic heater return water temperature may not drop be below 140˚F (60 ˚C) for all phases except phase 1.

11.11. Scale weight shall be recorded at 1-minute intervals and documented at the start and end of each test phase.

11.12. Test Run Procedure. The table below summarizes the phases that encompass a complete test run. Addition of cooling water during the testing is not allowed. A complete test run requires completion of all six phases of the test protocol, as described below.

IDC Pellet Hydronic Heater Test Procedure Summary	
Phase 1-Start-up	Startup per manufacturer's instructions. Pull off heat as needed when approaching operating temperature limit and ramp up to 100%
Phase 2 – Max Heat	100% heat load for 60 minutes at the load heat exchanger
Phase 3 – Low Heat	13% heat load at the load heat exchanger (+/-2%) for 120 minutes or after one cycle, whichever comes first. If unit begins to cycle off within 0-30 minutes of the start of Phase 3, 6 cycles must be completed in Phase 5. If the unit begins to cycle off within 31-60 minutes of the start of Phase 3, 4 cycles must be completed in Phase 5. If the unit begins to cycle off within 61-90 minutes of the start of Phase 3, 3 cycles must be completed in Phase 5. If the unit begins to cycle off within 91-120 minutes of the start of Phase 3, 2 cycles must be completed in Phase 5. If the unit does not cycle off during Phase 3, only 1 cycle must be completed in Phase 5.
Phase 4 -No load	No heat load for 45 minutes
Phase 5 – Cyclic operations	Forced cycling - Must complete 1-6 cycles, as determined by cycling time in Phase 2. • During on-cycle - cooling water is stopped, the system heats to the system operating limit temperature. • Off-cycle - Wait 30 minutes, then set cooling water at 100% heat load at the load heat exchanger until system reaches the system restart temperature. • Phase 4 ends after number of required cycles has been completed, and concludes the second 30 minute off period
Phase 6 - Recovery	• 100% heat load for 60 minutes

11.12.1. Phase – Start-up

11.12.1.1. Appliance Parameters

11.12.1.1.1. *Appliance temperature*. For the first run (Run #1) appliance temperature and firebox temperature shall be recorded.

11.12.1.1.1.1. Appliance and firebox temperatures shall be measured within 60 minutes of starting the test run and shall be reported for all test runs.

11.12.1.1.2. Water temperature requirements. Buffer tank and/or thermal storage shall not exceed 120 ˚F (48.9 ˚C) at the start of any test run. Average water temperature in the buffer tank and appliance at the start of testing shall be reported in the test report.

11.12.1.2. Appliance Operation during Phase 1

11.12.1.2.1. Following the start-up of the appliance, cooling water will be slowly adjusted to achieve high load operations. If the return water temperature appliance drops minimum operating temperatures during this phase then this is an invalid test run.

11.12.1.2.2. After the burner has stabilized at maximum burn rate and the average buffer tank temperature has reached 160 ˚F (71.1 ˚C), the cooling water flow shall be adjusted a necessary to achieve the nominal output rate.

11.12.1.3. End of Phase 1: Phase 1 shall end when the appliance is within appliance modulation temperature range and maximum heat load can be maintained for a period of at least five minutes without a change +/- 10˚F (5.6 ˚C) in average buffer tank and stack temperature.

11.12.2. Phase 2 – Maximum Heat Load. This phase commences immediately after Phase

11.12.2.1. *Appliance Parameters Phase 2.* During Phase 2, the unit must produce an average heat load output rate that is within ±10% of the manufacturer's rated heat output capacity. If average heat load output is not within these limits, the manufacturer's rated heat load output capacity is considered not validated and must be changed.

11.12.2.2. Appliance Operation during Phase 2.

11.12.2.2.1. The appliance shall fire at its maximum firing rate for the entire period. The average buffer temperature may not fluctuate more than 5˚F (2.8˚C) during this time period.

11.12.2.2.1.1. If at any time, the appliance temperature is rising and approaching the operating limit, the heat load shall be increased to prevent the appliance from cycling off or from modulating to a lower firing rate.

11.12.2.2.1.2. If at any time, the appliance temperature falls to less than 5˚F (2.78˚C) below the setpoint, the heat load rate shall be decreased until the appliance is within 5˚F (2.78˚C) of the appliance setpoint.

11.12.2.3. End of Phase 2: The end of Phase 2 is defined by a continuous period of 60 minutes of maximum heat load placed on the appliance.

11.12.2.3.1. Complete 60-minute average calculation from Phase 2 to confirm maximum heat load output as this will impact Phase 3 setting.

11.12.3. Phase 3 – Low Heat Load Phase. This phase commences immediately after Phase 2.

11.12.3.1. Appliance Operation during Phase 3. The system heat load at the load heat exchanger is reduced to 13% +/- 2% of the appliance's maximum rated heat load output. The appliance stays at this heat load for a period of 120 minutes or one complete cycle, whichever comes first. Ramp down to this heat load must be made in a period of fewer than 10 minutes. The test report shall indicate the time period used for ramp down.

11.12.3.1.1. Heat load on the system at the load heat exchanger is placed at 13% +/- 2% of maximum heat load output.

11.12.3.2. End of Phase 3: the end of Phase 3 is defined by a period of 120 minutes at 13% +/-2% heat load placed on the appliance or after one cycle, whichever comes first.

11.12.3.2.1. Determine the number of cycles that must be completed in Phase 5, using the following process:

11.12.3.2.1.1. If unit begins to cycle off within 0-30 minutes of Phase 2, 6 cycles must be completed in Phase 4.

11.12.3.2.1.2. If the unit begins to cycle off within 31-60 minutes of Phase 2, 4 cycles must be completed in Phase 4.

11.12.3.2.1.3. If the unit cycles off within 61-90 minutes of Phase 2, 3 cycles must be completed in Phase 4.

11.12.3.2.1.4. If the unit cycles off within 91-120 minutes of Phase 2, 2 cycles must be completed in Phase 4. If the unit does not cycle during Phase 2, only 1 cycle must be completed in Phase 4.

11.12.4. Phase 4 – No Heat Load Phase. This phase commences immediately after Phase 3.

11.12.4.1. Appliance Operation during Phase 4. Appliance heat load is 0%, and the appliance is turned off. The appliance stays at this 0% heat load for a period of 45 minutes. Ramp down to this heat load must be made in a period of fewer than 5 minutes. The test report shall indicate the time period used for ramp down.

11.12.4.2. *End of Phase 4.* The end of Phase 4 occurs when the appliance spends a minimum of 45 minutes at no heat load and the appliance cools to a setpoint where the appliance will cycle on at the beginning of Phase 5. This may be completed by manually setting a cooling load. Cooling load shall be completed prior to turning the appliance on for Phase 5. The cooling load should not exceed 120% of the maximum heat load output of the appliance.

11.12.5. Phase 5 – Cyclic Operations

11.12.5.1.*Appliance Operation during Phase 5.* This phase emulates the operation of the appliance, responding to a thermostat call at the start of this phase, power the appliance back on. This will be indicated by the appliance cycling on and restarting the burner, which can be indicated through control status, or starting of the combustion air/ induced draft fan. One cycle will start with a call for heat and then end once the appliance and buffer indicate a shutdown, cycles off, and has gone through one 30-minute idle period. A shutdown caused by reaching the system safety high limit temperature is not considered cycling off.

11.12.5.2. During Phase 5 the unit shall complete the number of cycles as determined in Phase 2, as defined in 11.11.3.2.1

11.12.5.2.1.The appliance must complete the required number of on/off cycles. During on-cycle - cooling water is stopped, the system heats to the system operating limit temperature. During the off-cycle – the system remains in idle for a period of 30 minutes with no heat load. After the 30-minute period, set cooling water for 100% heat load until the system minimum operating temperature is reached, and the appliance's controls acts to restart the burner.

*11.12.5.2.2.*If, during this test, the appliance shuts down on the high-temperature safety control, requiring a manual reset, the test is a failed run.

11.12.5.3.End of Phase 5: the end of Phase 5 occurs when the 30-minute period after the final cycling event is completed, and the appliance is in an off-cycle.

11.12.6. Phase 6 – Response to Setback Conditions.

11.12.6.1.*Appliance Operation during Phase 6.* For 60 minutes, the cooling water shall be adjusted for a heat load of 100% of the nominal full-load output. If the return water temperature in the system (heater and buffer tank) drops below the 120 ˚F (48.9 ˚C), cooling will stop temporarily until the heater returns to within 10 ˚F (5.6 ˚C) of its modulation temperature per the User Guide. Cooling water will then be adjusted to continue at 100% heat load, or nominal load. The time at which cooling is stopped and continued shall be recorded.

11.12.6.2.*End of Phase 6.* the end of Phase 6 occurs when after 60 minutes from the start of the phase

11.12.7. End of the Test Run. The test runs end when all six phases of the test run have been completed in sequence.

11.12.7.1. Test Run Completion. At the end of the Phase 6, stop the particulate sampling instruments and measurements required for the efficiency determination, and record the run time and all final measurement values.

11.12.7.2. At the end of the test run, continue to apply a thermal load to the heater to allow the remaining fuel to safely be consumed if necessary. No measurements are required during this period.

11.13. *Test run requirements.* The following are the pre-testing appliance use requirements for each test run.

11.13.1. *Consecutive Test Runs*. Consecutive test runs may be conducted, provided that the following requirements are met:

11.13.1.1. Run 1 – appliance can only be run for a shake down test to verify proper installation. The unit cannot run for period greater than 8 hours within the 48-hour period proceeding commencement of official tests runs. Record average firebox temperature within 1 hour of the start of test by measuring the central point along all walls of the firebox.

11.13.1.2. Run 2 – shall not operate for a minimum of 8 hours from the conclusion of Run 1 before commencing Run 2. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 2. All coals and ash must be removed before commencing Run 2.

11.13.1.3. Run 3 – shall wait a minimum 8 hours from the conclusion of Run 2 before commencing Run 3. Appliance coals and ash can remain in the appliance until 1 hour before conducting Run 3. All coals and ash must be removed before commencing Run 3.

11.14. *Failure to Operate at All Test Conditions*. If an appliance cannot operate in all of the test Phases without achieving an appliance temperature that causes the safety high limit to be activated, requiring a manual reset, the test is a failed run. After two failed test runs, the unit is deemed to have failed the test, and the unit cannot be certified with this test method.

11.15. *Test Series completion*. A complete test series is defined as the successful completion of three full test runs, as specified in Section 11.11 of this method.

11.15.1. If the appliance fails more than the two test runs, the appliance has failed the certification test and cannot be certified for compliance without modification to the appliance design.

11.16. *Additional Test Runs*. The testing laboratory may conduct more than three test runs but no more than five runs. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated from the reporting requirements of this method.

12. *Calculation of Results – Calculation of Results*

NOTE: If a TEOM is used for PM measurement, proportioning of emission factors and rates per phase according to Appendix A, variables will have subscript added to determine the relevancy of phase i.e. $E_{T(P1)}$ indicates Total particulate emissions for Phase 1 and $E_{g/hr(P2)}$ indicates emissions factor in grams per hour for Phase 2.

12.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide shall be calculated using the following methodology and reported in grams per hour, grams per kilogram and pounds per million British Therma Unit (Btu) per hour based on heat output:

12.1.1. Two PM measurements shall be reported

12.1.1.1. 60-minute reporting. Emissions from the first sixty minutes shall be reported. The 60-minute periods begins at match light. 60-minute data shall be collected and reported as a separate ASTM 2515-11 train or the TEOM (if applicable) data calculated per the SOP.

12.1.1.2. Integrated Result. The results two, dual ASTM E2515-11 trains, shall integrate into a single result the appliance performance over the six phases of this test method's operational protocol.

12.2.Particulate Matter Emissions Rates. After the test is completed determine the particulate matter emissions rate E_r in accordance with ASTM E2515-11 for each test run. If using ASTM E2515-11 for one-hour data, prepare calculations for each first hour of operation.

12.3. Nomenclature

BR – average dry fuel burn rate, lb./min
CA – Carbon
HY - Hydrogen
OX - Oxygen
C_p – Specific heat of water in Btu /lb., ˚F
C_{steel} − Specific heat of steel (0.1 Btu/ lb., ˚F)
E_T – Total particulate emissions for the full test run as determined per ASTM E2515-11 in grams
$E_{g/MJ}$ – PM Emissions rate in grams per megajoule of heat output
$E_{lb/MMBtu\ output}$ – PM Emissions rate in pounds per million Btu of heat output
$E_{g/kg}$ – PM Emissions factor in grams per kilogram of dry fuel burned
$E_{g/hr}$ – PM Emissions factor in grams per hour
E_{Rco} – CO emission rate, g/hr.
EIi – Average CO emission index for interval i
E_{ICO} – CO emission index, g/kg dry fuel
EIco,avg – Average CO emission index for the run
HHV – Higher heating value of fuel = Use accredited test results
LHV – Lower heating value of fuel = Use accredited test results
M − Mass flow rate of water in lb./min (kg/min)
MC – Fuel moisture content, % dry basis
MC_i – Average moisture content as determined by ultimate/proximate analysis
PCTCO2– average CO_2 in the dry flue gas (%)
PPMco -average CO in the dry flue gas (ppm)

Q_{out} − Total heat output in BTU's (megajoules)
$Q_{out(p2)}$ - Total heat output in BTU's (megajoules) in Phase 2
$Q_{out(p3)}$ - Total heat output in BTU's (megajoules) in Phase 3
$Q_{out(p6)}$ - Total heat output in BTU's (megajoules) in Phase 6
Q_{in} − Total heat input available in test fuel charge in BTU (megajoules)
$Q_{in(p2)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 2
$Q_{in(p3)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 3
$Q_{in(p6)}$ - Total heat input available in test fuel charge in BTU (megajoules) in Phase 6
SC – change in scale mass during measurement interval, lb.
$t_{(i)}$ − Data sampling interval in minutes
T1 – Temperature of water at the inlet on the supply side of the heat exchanger, ˚F (˚C).
T2 – Temperature of the water at the outlet on the supply side of the heat exchanger, ˚F (˚C).
T3 – Temperature of cooling water at the inlet to the load side of the heat exchanger, ˚F (˚C).
T4 – Temperature of cooling water at the outlet of the load side of the heat exchanger, ˚F (˚C).
T5 – Temperature of the hot water supply as it leaves the appliance, ˚F (˚C).
T6 – Temperature of return water as it enters the appliance, ˚F (˚C).
TI_{avg} − Average temperature of the appliance and water at start of the test, ˚F (˚C).
TF_{avg} – Average temperature of the appliance and water at the end of the test, ˚F (˚C)
TIS1 – Temperature measurement 1 in buffer tank positioned at the top 1/6th volume portion of the tank, ˚F (˚C).
TIS2 − Temperature measurement 2 in buffer tank positioned at the second 1/6th volume portion of tank, below TIS1 and above TIS3, ˚F (˚C).
TIS3 – Temperature measurement 3 in buffer tank positioned at the third 1/6th volume portion of the tank, below TIS2 and above TIS4, ˚F (˚C).
TIS4 − Temperature measurement 4 in buffer tank positioned at the fourth 1/6th volume portion of the tank, below TIS3 and above TIS5, ˚F (˚C).
TIS5 − Temperature measurement 5 in buffer tank positioned at the fifth 1/6th volume portion of the tank, below TIS4 and above TIS6, ˚F (˚C).
TIS6 − Temperature measurement 6 in buffer tank positioned at the bottom 1/6th volume portion of the tank below TIS5, ˚F (˚C).
TISavg − Average temperature of the 6 sensor buffer tank at the start of the test, ˚F (˚C).
TFSavg − Average temperature of the 6 sensor buffer tank at the end of the test, ˚F (˚C).
V_{blr} – appliance water capacity, gallons
V_i – Volume of water indicated by a totalizing flow meter at the ith reading in gallons (liters)
V_f – Volumetric flow rate of water in heat exchange system in gallons per minute (liters/min)

σ – Density of water in pounds per gallon
σI – Density of water at average temperature of the appliance and water at start of measurement interval, pounds per gallon
σF – Density of water at average temperature of the appliance and water at end of measurement interval, pounds per gallon
W_{fuel} – Fuel charge weight in pounds (kg)
W_i – Weight of fuel in pounds (kg)
W_{app} − Weight of empty appliance in pounds (kg)
W_{wa} – Weight of water in the supply side of the system in pounds (kg)
WStorageTank − Weight of the buffer tank empty in pounds (kg)
WWaterStorage − Weight of the water in the buffer tank at TISavg in pounds (kg).
ΔT – Temperature difference between water entering and exiting the heat exchanger
η_{del} – Delivered heating efficiency in percent
$\eta_{del(p2)}$ Delivered Efficiency of Phase 2, percent
$\eta_{del(p3)}$ Delivered Efficiency of Phase 3, percent
$\eta_{del(p6)}$ Delivered Efficiency of Phase 6, percent
Θ – Total length of test run in hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X

12.4. Determine Heat Input.

12.4.1. Average Fuel Load Content. Determine average fuel load content using HHV and LHV results of the fuel energy density analysis (ultimate/proximate analysis) per test run and Phases 2,3, and 6.

$Q_{in} = (W_{fuel}/(1+(MC/100))) \times HHV$, BTU
$Q_{in\ LHV} = (W_{fuel}/(1+(MC/100))) \times LHV$, BTU
$Q_{inPhaseX} = (W_{fuelPhaseX}/(1+(MC/100))) \times HHV$, BTU
$Q_{in\ LHVPhaseX} = (W_{fuelPhaseX}/(1+(MC/100))) \times LHV$, BTU

12.5. Determine Heat Output per test run and Phases 2,3, and 6

Q_{out} = Σ [Heat output determined for each sampling time interval] + Change in heat stored in the appliance over the entire phase + Change in heat in storage tank over the entire phase.

Note: The subscript (i) indicates the parameter value for sampling time interval ti. This sampling time interval is typically 1 minute.

$$Q_{out} = \Sigma[Cpi \cdot \Delta Ti \cdot Mi \cdot ti] + (Wapp \cdot Csteel + Wwater \cdot Cpa) \cdot (TFavg - TIavg) + (WStorageTank \cdot Csteel + WWaterStorage \cdot Cpa) \cdot (TFSavg - TISavg) \text{ Btu (MJ)}$$

Mi = Mass flow rate = gal/min x density of water (lb./gal) = lb./min
Mi =Vfi · σi, lb./min

Note: the above calculation assumes that the cooling water flow is measured on a volumetric basis.
$\sigma i = (62.56 + (-.0003413 \times T3i) + (-.00006225 \times T3i^2)) 0.1337$, lbs./gal
$Cp = 1.0014 + (-.000003485 \times T3i)$ Btu/lb, ºF
Csteel = 0.1 Btu/lb, ºF
$Cpa = 1.0014 + (-.000003485 \times (TIavg + TFavg)/2)$, Btu/lb-ºF

12.5.1. Determine total heat output rate as:

Total Heat Output Rate = Q_{out}/Θ, BTU/hr.

12.5.2. Determine heat load rate as:
Heat load rate = $\Sigma[Cpi \cdot \Delta Ti \cdot Mi \cdot ti]/ \Theta$
Phase X Heat load rate: $\Sigma_{(PhaseX)}[Cpi \cdot \Delta Ti \cdot Mi \cdot ti]/ \Theta_{(x)}$

12.5.3. Delivered Efficiency - delivered efficiency over the six phases is representative of annual efficiency. Determine delivered efficiency as:

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

12.5.4. Determine Steady Heat Load Period Delivered Efficiency.
Determined For efficiency of high and low heat loads, determine the delivered efficiency of the individual steady heat load phases, Phases 2,3, and 6.
$\eta_{del(p2)} = Q_{out(p2)}/ Q_{in(p2)} \times 100$, %
$\eta_{del(p3)} = Q_{out(p3)}/ Q_{in(p3)} \times 100$, %
$\eta_{del(p6)} = Q_{out(p6)}/ Q_{in(p6)} \times 100$, %
Note: If the system is able to satisfy a 100% heat load for phase 6 without cycling on the appliance, then assumed delivered efficiency for phase 6 is 98%.

If no fuel is used in Phase 6, as in the hydronic heater did not cycle on and fire up, and heat load is met, delivered efficiency for phase 6 ($\eta_{del(p6)}$) is considered to be 100%, not including losses through pipe or water jacket. It must be clearly documented that a reported 100% delivered efficiency for phase 6 ($\eta_{del(p6)}$) is because the hydronic heater met the full heat load for Phase 6 without cycling on and firing up.

12.5.5. Determine emission rates and emission factors as:

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

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

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

$E_{g/hr} = E_T/\Theta$, g/hr

12.6. Determination of CO Emissions Per Phase

In this section CO emission rate and CO emission index are calculated for each phase in 10-minute intervals. For each interval this is based on average burn rate, flue CO and CO_2 for the period.

12.6.1. Determination of Dry Fuel burn rate During each Interval

Density of water at the start and end of each 10-minute interval shall be calculated using the equation in section 12.5 based on average temperature of the appliance.

$BR = (100/(100+MC))*(SC- V_{blr} * (\sigma F - \sigma I))/10$

If the burn rate for any interval is equal to or less than zero or if the burner is obviously not firing during that part of the test, the burn rate and CO emission rate during that interval shall be assigned a value of zero. For any 10-minute intervals where the burner is transitioning between on and off or off and on, include active burn data in the previous 10-minute interval if active period is less than 5 minutes or include as its own 10-minute interval if active period is greater than 5 minutes.

12.6.2. Intermediate Calculations

The following intermediate calculations and constants are defined in this section for convenience. These results are used in calculations in following section.

x= CA/12
y = HY
z = OX/16

The following parameters shall be calculated for each interval over which the burn rate is not zero.

gamma_n = x + y/4 -z/2
beta_n = ((100 * x * PPMco)/(1000000 * PCTCO2+100 * PPMco))
alpha_n = ((100 * (x-beta_n)/PCTCO2)-x-(beta_n/2)-gamma_n * 3.76)/(gamma_n * 4.76)

MFco_n = beta_n- kmoles of CO produced when 100 kg dry fuel is burned
MFCO2_n = x-beta_n - kmoles of CO_2 produced when 100 kg dry fuel is burned
MFO2x_n = (alpha_n * gamma_n+beta_n/2) - kmoles of O_2 produced when 100 kg dry fuel is burned
MFNI_n = (1+alpha_n) * gamma_n * 3.76 - kmoles of N_2 produced when 100 kg dry fuel is burned
DryGas = MFco_n + MF_CO2_n + MF_O2_n + MFNI_n - total kmols of dry gas produced per 100 kg of dry fuel burned

DryGasRate = (BurnRate*60*0.454*DryGas)/100 - Kmol of dry gas produced per hour

Informative note – kmol used here refers to kilogram mols.

12.6.3. Calculation of CO Emission Rate and CO Emission Index
For each interval during which the burn rate is not zero, calculate the CO emission rate and emission index as follows:
ERco = (PPMco * DryGasRate * 28 * 454)/(1000000 * 0.454) - CO emission rate, g/hr
EIco = (DryGas * PPMco * 1000 * 28)/(100 * 1000000) - CO emission index, g/kg dry fuel

12.6.4. CO Emissions Test Run Calculations
For each run the average CO emission rate shall be calculated as the average of the CO emission rates during each of the active burn period 10-minute intervals, g/hr. Intervals for which the burn rate is zero shall not be included in this average.
For each run the average CO emission index shall be calculated as the burn rate weighted average of the emission indices during each of the active burn period 10-minute intervals, g/kg. This calculation can be expressed as:

$$EIco, avg = \frac{\sum_i EI_i \cdot BR_i}{\sum_i BR_i}$$

13. *Reporting Requirements*. The report shall include the following:

13.1. Introduction - no portion of the introduction may be claimed as CBI.

13.1.1. Purpose of test: certification, audit, efficiency, research, and development

13.1.2. Name and location of the laboratory conducting the test.

13.1.3. Wood appliance identification – manufacturer, model number/name, design type, description of the appliance tested, appliance condition, and date of receipt.

13.1.4. Test information – location of testing, date of tests, sampling methods used, number of test runs, a statement detailing any previous testing completed on the wood appliance.

13.1.5. A list of participants, their roles, and any observers present for the tests. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

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

13.2. Summary and Discussion of Results - no portion of the introduction may be claimed as CBI.

13.2.1. Record summary results in tables 1A, 1B, and 1C. Table of results to include test run number, average burn rate for entire run, particulate emission rate for full run, particulate emission rate for start-up, carbon monoxide emission rate for a full run, carbon monoxide for startup, efficiency, burn time – total and by phase.

13.2.2. If the TEOM is used for the entire test, the report shall contain the following: For each test run use the TEOM to apportion filter PM data for the six individual phases. Calculated results for the emissions reported as total emissions in grams, grams per hour.

13.2.3. If a TEOM is used, provide a plot of PM emission rate in grams/hour vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

13.2.4. Summary of other data – test facility conditions such as test facility temperature, air velocity and humidity, catalyst averages, pretest fuel weights, test fuel charge weights – total and by phase.

13.2.5. Two measurements shall be reported

13.2.5.1. Start-up. Emissions from powering on the appliance until the end of the start-up phase shall be collected and reported as a separate element using two ASTM E2515-11 trains. One-hour data shall be reported by a third ASTM E2515-11 train or the TEOM data calculated per the SOP.

13.2.5.2. Integrated Result. The results two, dual ASTM E2515-11 trains shall integrate into a single result the appliance performance over the six phases of this test methods operational protocol.

13.3. Discussion. - no portion of the discussion may be claimed as CBI.

13.3.1. Discussion shall include detailed information describing each test conducted on the appliance:

13.3.1.1. How the test was run

13.3.1.2. Specific test run problems and solutions

13.3.1.3. Test run result

13.3.1.4. Deviations

13.4. Process description:

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

13.4.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight and volume adjustments. No portion of this section can be CBI.

13.4.3. Firebox configuration – At a minimum to include air supply locations and operation, air supply introduction location, refractory location and dimensions, catalyst location, baffle and by-pass location and operation (include line drawings or photographs)

13.4.4. Process operation during test – shall supply details on air supply settings and adjustments. No portion of this section can be CBI.

13.4.5. Test fuel properties – species, density, fuel moisture, fuel temperature, and load details. No portion of this section can be CBI. Also, a description of test fuel sourcing, handling and storage practices shall be included.

13.4.6. Sampling. No portion of this section can be CBI.

13.4.6.1. A description of the test procedures and test equipment including a schematic or other drawing showing the location of all required sampling equipment.

13.4.6.2. Describe sampling location relative to appliance, include drawing or photographs.

13.4.6.3. Provide data on sampling blanks.

13.4.6.4. Sampling and Analytical procedures. Detailed description of procedures followed by laboratory personnel in conducting the certification test.

13.5. Quality Control and Assurance Procedures. No portion of this section can be CBI.

13.5.1. Calibration procedures and results certification procedures, sample and analysis procedures.

13.5.2. Test method quality control procedures to include leak-checks, volume meter checks, stratification (velocity) checks, proportionality results.

13.6. Appendices – No data contained in the appendices can be claimed as CBI.

13.6.1. Results and Example Calculations. Complete summary tables and accompanying calculations.

13.6.2. Raw data. Copies of all files or sheets for sampling measurement, temperatures records, and sample recovery data.

13.6.3. Test Equipment Calibration Results. Summary of all calibrations, check and audits pertinent to the certification.

13.6.4. Sampling and Operation Records. Copies of all uncorrected records of activities not included in raw data sheets (e.g. appliance door open, times and durations).

13.6.5. User Guide. Appliance instructions for operating the device during the test following the User Guide specifications detailed in Section 9.3.

13.6.6. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any). An explanation of the deviations, additions, or exclusions shall be provided along with an analysis as to why these elements had no impact.

13.6.7. All required data and applicable blanks for each test run shall be provided in spreadsheet format both in the printed report and in a computer file such that the data can be easily analyzed and calculations easily verified. Formulas used for all calculations shall be accessible for review.

13.6.8. For each test run, if used: report TEOM flow and temperature and verification of all TEOM parameters presented in the TEOM 1405 SOP.

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

Table 1A – Must complete a table for each test run, minimum of three

Data Summary Part A - Run 1

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 2

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								
Total								

Data Summary Part A - Run 3

Phase	Target Load	Actual Load	Phase Duration	Wood Consumed	Total Heat Output	Total Heat Input	Delivered Efficiency	CO Rate
	Btu/hr.	Btu/hr.	hours	Lbs.	Btu	Btu	%	g/min.
2								
3								
6								

Total								

Table 1B – Must complete a table for each test run, minimum of three

Data Summary Part B – 60-minute test results

		Q_{out}	E_T	E	E	E_{Rco}	E_{Ico}
Run No	Date	Heat Output	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor
		Btu	g	lb/MMBtu Out	g/MJ	g/hr.	g/kg
1							
2							
3							

Table 1C Data Summary – Averages

Data Summary – Part 1

			Θ	W_{fuel}	MC_{ave}	Q_{in}	Q_{out}
Run No	Date	Fuel Gross Ca. Value	Test Duration	Wood Weight as-fired	Wood Moisture	Heat Input	Heat Output
-		Btu/lb.	Hrs.	Lbs.	%DB.	Btu.	Btu.
1							
2							
3							
Average							

Data Summary – Part 2

		E_T	E	E	$E_{PMg/hr}$	$E_{g/kg}$	$E_{CO\ g/hr}$	$E_{Cog/kg}$
Run No	Date	Total PM Emissions	PM Output Based	PM Output Based	PM Rate	PM Factor	CO Rate	CO Factor
		g	Lb./MM Btu Out	g/MJ	g/hr.	g/kg fuel	g/hr.	g/kg fuel
1								
2								
3								
Average								