A Test Method for Certification of Pellet-Fired Hydronic Heating Appliance Emissions Based on an Integrated Duty Cycle (IDC) Load Profile: Measurement of Particulate Matter (PM) using a TEOM, Carbon Monoxide (CO), Carbon Dioxide (CO2), Oxygen (O2), and Heating Efficiency

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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 must 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 (Standard 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 Wood Heaters
- 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 with or without the use of an external buffer tank(s) (sometimes called thermal storage) external to the appliance. 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 denote any heat transfer liquids approved for use by the manufacturer.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide (CO) emissions, and delivered heating efficiency.

1.3. Particulate emissions are measured using the Tapered Element Oscillating Microbalance (TEOM) continuous PM method using procedures detailed in *NYSERDA*

Standard Operation Procedures for using a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces. Dilution tunnel configurations follow procedures specified in ASTM E2515-11 *Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel* with modifications as noted in this procedure.

1.4. Carbon monoxide emissions are measured in the stack.

1.5. Carbon dioxide emissions are measured in the stack.

1.6. 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. The heat output determination considers changes in the appliance's temperature and thermal storage system from the start to the end of the run. Delivered efficiency does not 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 is included in the efficiency determination.

1.7. Products covered by this test method include pressurized and non-pressurized hydronic heating, 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 heat structures such as homes, barns, schools, and greenhouses. They also provide heat for domestic hot water, spas, and swimming pools.

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

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

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

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

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

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

1.10. Analyte. Particulate matter (PM). No CAS number was assigned. Carbon monoxide (CO) CAS no. 630-08-0. Carbon dioxide (CO_2) CAS no. 124-38-9.

1.11. Data Quality Objectives.

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

1.11.2. Measurement of emissions and heating efficiency provides a consistent basis for comparing product performance that is useful to the consumer. It is also required to relate emissions produced to useful heat production.

1.11.3. This laboratory method is intended to capture operating periods representative of actual field use without excessive test burden.

2. *Referenced Methods*

2.1. ASTM D1102 Test Method for Ash in Wood.

2.2. ASTM E871 Standard Test Method for Moisture Analysis of Particulate Wood Fuels.

2.3. ASTM E873 Standard Test Method for Bulk Density of Densified Particulate Biomass Fuels.

2.4. ASTM E2515: Standard Test Method for Determination of Particulate Matter Emissions Collected in a Dilution Tunnel (latest approved EPA version).

2.5. CAN/CSA-B415.1-10: Performance Testing of Solid-Fuel-Burning or the latest approved EPA version.

2.6. ISO 16968:2015: Solid Biofuels – Determination of Minor Elements.

2.7. ISO 16948:2015: Solid Biofuels – Determination of Total Content of Carbon, Hydrogen, and Nitrogen.

2.8. ISO 16994:2016: Solid Biofuels – Determination of Total Content of Sulfur and Chlorine.

2.9. ISO 18125:2017: Solid Biofuels – Determination of Calorific Value.

2.10. ISO 18135:2017: Solid Biofuels Sampling.

2.11. NIST Monograph 175, Standard Limits of Error.

2.12. "NYSERDA Standard Operation Procedures for using a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces" using the most recent TEOM SOP in the EPA docket at https://www.regulations.gov/docket/EPA-HQ-OAR-2016-0130

2.13. US EPA Method 3A.

2.14. US EPA Method 10.

2.15. US EPA TID-024 – Performance Test Calculation Guidelines.

3. *Summary of Test Method*

3.1. *Carbon Dioxide*. CO_2 concentrations as measured in the stack and used to calculate efficiency per CSA B415.

3.2. *Carbon Monoxide*. CO concentrations as measured in the stack and used to calculate efficiency per CSA B415 with modifications detailed in Section 9.3 of this test method.

3.3. *Delivered Efficiency.* Efficiency is measured by determining the fuel energy input, and the amount of useful appliance heat output delivered to the home.

3.4. *Dilution Tunnel*. PM 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* (revised June 30, 2017) with exceptions as defined in Section 9.1. The flow rate in the dilution tunnel is maintained at a constant level throughout the test cycle and accurately measured.

3.5. *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 a fully heated state. The second and third test runs may start with a firebox slightly warmer than the first run. For the second and third runs, there are no temperature requirements. However, the firebox must be passively cooled overnight – no secondary heating instruments may be placed in the firebox between test runs to raise the firebox temperature artificially. The appliance is operated at various heat loads representing start-up emissions, high heat load, low heat load, cycling, idling, and recovery from the nighttime setback. The appliance is operated through six heating phases during the test run. A minimum of three complete and valid test runs are averaged to determine the test results to complete the certification test. For automatic feed systems, fuel is fed as determined by appliance delivery systems.

3.6. *Particulate Matter*. Real-time PM Measurements are made with a Tapered Element Oscillating Microbalance (TEOM) instrument, Thermo model 1405-D TEOM, operated using the specifications detailed in the document titled, *"NYSERDA Standard Operating Procedures for Using TEOM 1405-D in a Dilution Tunnel with wood-fired stoves, hydronic heaters, or furnaces"* following the most recent TEOM SOP in the EPA docket at https://www.regulations.gov/docket/EPA-HQ-OAR-2016-0130

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

4. *Definitions*

4.1. Aborted Test Run – The run shall be considered aborted if a force majeure event occurs, such as a power outage or equipment operation failure. Aborted test runs are treated differently than incomplete or invalid test runs.

4.2. 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.

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

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

4.5. Calibration Curve – The relationship between an NDIR analyzer's output to the concentrations of a range of calibration gasses.

4.6. Calibration Gas – The gas mixture containing a known concentration of a subject gas and produced and certified in accordance with "EPA Traceability Protocol for Assay and Certification of Gaseous Calibration Standards," September 1997, as amended August 25, 1999, EPA-600/R-97/121 or more recent updates. The tests for analyzer calibration error, drift, and system bias require using calibration gas prepared according to this protocol. If a zero gas is used for the low-level gas, it must meet the requirements under the definition for "zero air material" in 40 CFR 72.2 in place of being prepared by the traceability protocol.

4.7. Calibration span – The upper limit of the analyzer's range that is set by the choice of the high-level calibration gas. No valid run average concentration may exceed the calibration span. To the extent practicable, the measured concentrations should be between 20 to 100 percent of the instrument calibration span.

4.8. Centroidal Area – The central area of the stack or duct that is 1" in diameter.

4.9. Cooling Water – Cold water from an external source ("city water") is used to extract the heat load.

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

4.11. Data recorder – The equipment that permanently records the electronic signals reported by the signal-generating equipment, such as but not limited to thermocouples, pressure gauges, and gas analyzers.

4.12. 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.

4.13. Drift – Difference between pre and post-run calibration system bias (or system calibration error) checks at a specific calibration concentration level.

4.14. Emission Factor – The emission of a pollutant expressed in mass per unit of energy (typically) output from the appliance (e.g., lb./MMBtu).

4.15. Emission Rate – The emission of a pollutant expressed in mass per unit time.

4.16. Firebox – The chamber in the appliance in which the test fuel charge is fed into and combusted.

4.17. Flue Gas Measurement System – All the equipment used to determine the measured concentration. This system comprises five major subsystems: sample acquisition, sample transport, sample conditioning, gas analyzer, and data recorder.

4.18. Gas analyzer – Instrument that measures and transmits an electronic signal output proportional to a measured gas concentration.

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

4.20. 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.).

4.21. High-level gas – Calibration gas with a concentration that is at least 90% of the instrument's full-scale range.

4.22. Hydronic Heater – Same as appliance definition.

4.23. Idle – A control state where the hydronic heater is not feeding fuel 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 the hydronic heater activates the burner. This may be visually indicated by a LED signal, an alert, or a change in control status on the hydronic heater.

4.24. Incomplete Test Run – Any test run that does not successfully complete all six test phases continuously due to stopped fuel combustion or other appliance issues, as detailed in Section 12.20.

4.25. Invalid Test Run – Any complete or partial test that does not meet the specifications detailed in this test method as the fault of the system operation.

4.26. Low-level gas – Calibration gas with a near-zero concentration of the full-scale range of the gas analyzer.

4.27. Manufacturer's Rated Heat Output Capacity − The value in Btu/hr. (MJ/hr.) that the manufacturer specifies that a particular appliance and buffer model can supply in steady-state at its design capacity, as verified by data from the appliance heat output assessment test run.

4.28. Mid-level gas – Calibration gas with a concentration of 40-60% of the full-scale range of the gas analyzer.

4.29. NIST – National Institute of Standards and Technology.

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

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

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

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

4.34. System – A combination of the appliance and buffer and required interconnections and controls.

4.35. System calibration mode – The introduction of calibration gases into the measurement system at the flue gas inlet probe upstream of conditioning components, filtration, and flue gas sample transport equipment.

4.36. Temperature, Average Buffer – An average of all three test temperature sensors internal to the tank. This value does not include temperature sensors which the manufacturer may add for control purposes. If more than one buffer tank is required, then average all sensors.

4.37. Temperature, Average Hydronic Heater – Average of the hydronic heater supply and the return water entering the hydronic heater.

4.38. Temperature, cooling water entering load – Temperature of cooling water entering the heat exchanger.

4.39. Temperature, cooling water exiting load – Temperature of cooling water leaving the heat exchanger.

4.40. 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 must be 140 ˚F (60 ˚C) or higher if specified by the manufacturer for all phases except Phase 1. If at any time after Phase 2, the temperature of the return water entering the hydronic heater falls below 140 ˚F (60 ˚C), the reports must document and explain the occurrence. This data may or may not invalidate the run based on data review.

4.41. Temperature, Hydronic Heater Modulation – On rising hydronic heater temperature, the temperature is measured at the control sensor point at which the control acts to reduce the combustion air input from the full fire level.

4.42. Temperature, Hydronic Heater Operating Limit – On rising hydronic heater temperature, the temperature at the control sensor point at which the controller initiates a burner shutdown, idle, or off state.

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

4.44. Temperature, Return water entering the hydronic heater – Temperature of the water downstream of the mixing valve, entering the return connection on the hydronic heater.

4.45. Temperature, Return water flowing out of the heat exchanger – Temperature of the water at the exit of the heat exchanger and returning to the hydronic heater.

4.46. 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.

4.47. Temperature, Supply water into the heat exchanger – Temperature of the heated water at the entrance of the heat exchanger located on the supply side.

4.48. Temperature, Supply water leaving the hydronic heater – Temperature of the heated water leaving the hydronic heater to the heating load.

4.49. Temperature, System Operating Limit – On rising buffer temperature, the temperature at the control sensor point or points at which the controller initiates a burner shutdown. This typically will be below the hydronic heater operating limit temperature.

4.50. Temperature, System Restart – On falling buffer temperature, the tank temperature at the control sensor point at which the controller initiates a restart of the burner.

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

4.52. Temperature Range, System – The temperature range between the system restart and the system operating limit.

4.53. 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.

4.54. Test Facility – The area where the heating system is installed, operated, and sampled for emissions.

4.55. Test Run – An individual emission test encompasses the time required to complete all specified phases of the test profile.

4.56. Test Run Delivered Efficiency – The delivered efficiency of a test run.

4.57. Test Series – The complete data set for all test runs conducted on the system.

4.58. Valid Test Run – A complete test run that complies with all requirements detailed in this test method.

5. Interferences

5.1. CO - Reserved.

5.2. PM - Reserved.

6. *Significance and Use*

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

6.2. When approved by state or federal agencies, these measurements are often required to determine compliance with regulations and statutes.

6.3. 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.

6.4. 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 useful heat production.

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 before performing this test method.

7.2. These tests involve the combustion of wood, which releases substantial amounts of heat and combustion products. Appropriate precautions must be taken to protect personnel from burn hazards and the respiration of products of combustion. Exposure of personnel to unsafe levels of carbon monoxide must be avoided. The use of continuous ambient carbon monoxide monitoring or a CO alarm system is strongly recommended.

7.3. Refer to section 5.0 of EPA Method 10 for additional safety considerations.

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

8.1. *Anemometer.* A device capable of detecting air velocities less than 0.10 m/sec (20 ft/min) for measuring air velocities within 2 ft. (0.6 m) of the appliance.

8.2. *Appliance Flue.*

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) above the top of the platform scale. 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.

8.2.2. 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 a chimney for home installation. Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test.

8.2.3.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).

8.3. *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.

8.4. *Barometer.* Aneroid or other barometers capable of measuring atmospheric pressure to within 0.10 in. Hg (2.5 mm Hg). NOTE: The barometric pressure reading may be obtained from a nearby National Weather Service station. In this case, the station value (the absolute barometric pressure, not corrected to sea level pressure) shall be requested, and an adjustment for elevation differences between the weather station and sampling point shall be made at a rate of minus 2.5 mm (0.1 in.) Hg per 30 m (100 ft) elevation increase or plus 2.5 mm (0.1 in.) Hg per 30 m (100 ft.) for elevation decrease.

8.5. *Buffer Temperature Sensors*. Three temperature sensors must be located internally per buffer tank to determine the average temperature of the buffer in real-time. The tank volume must be divided into three equal volumes, and a sensor must be located at the vertical center of each volume. The sensors must 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 the top connections on the tank to enable the insertion of a 3-point probe for this purpose. The sensors must not be attached to the surface of the tank. Alternative buffer temperature sensor positioning requires written consent from proper regulatory authorities.

8.6. *Calibration Gases.* Low-level, mid-level, and high-level gas mixtures of known concentration.

8.7. *CO Gas Analyzer.* A continuous nondispersive infrared (NDIR) analyzer, which measures CO concentration in the flue gas stream. The use of a dual-range analyzer is acceptable. These analyzers are often equipped with automated range-switching capability so that when readings exceed the full-scale of the low measurement range, they are recorded on the high range. As an alternative to using a dual-range analyzer, you may use two segments of a single, large measurement scale to serve as the low and high ranges. When two ranges are used, you must quality-assure both ranges using the proper sets of calibration gases.

8.8. *CO2 Gas Analyzer.* A continuous NDIR analyzer, that measures the CO_2 concentration in the flue gas stream. The use of a dual-range analyzer is acceptable. These analyzers are often equipped with automated range-switching capability so that when readings exceed the full scale of the low measurement range, they are recorded on the high range. As an alternative to using a dual-range analyzer, you may use two segments of a single, large measurement scale to serve as the low and high ranges. When two ranges are used, you must quality-assure both ranges using the proper sets of calibration gases.

8.9. Dilution Tunnel must meet the requirements of ASTM E2515-11, clauses 6.1.6 and 9.2.

8.10. Dilution Tunnel temperature and relative humidity/dewpoint 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. Alternatively, you may use an instrument capable of measuring tunnel dewpoint in the expected temperature range (60˚F to 170˚F or 15.6 to 76.7˚C) to within 0.9 ˚F (0.5 ˚C) at 35˚C.

8.11. *Flue Gas Sample Probe*. Stainless steel or other approved material of sufficient length to measure the sample point in the stack.

8.12. *Flue Gas Particulate Filters*. The filter(s) must be made of material that is non-reactive to the gas being sampled and placed upstream of the gas analyzer.

8.13. *Flue Gas Sample Line*. The sample line from the probe to the conditioning system/sample pump should be made of Teflon or other material that does not adsorb or otherwise alter the sample gas.

8.14. *Flue Gas Calibration Line*. The sample line from the flue gas probe to the calibration gas must be made of Teflon or other material that does not adsorb or otherwise alter the sample gas.

8.15. *Flue Gas Conditioning Equipment*. A condenser, dryer, or another suitable system that removes moisture, condensable organic material, and particulate continuously from the sample flue gas.

8.16. *Flue Gas Sampling Pump*. A leak-free pump is needed to pull the sample gas through the system at a sufficient flow rate to minimize the measurement system's response time. The pump must be constructed of a material that is non-reactive to the gas being sampled.

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

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

8.19. *Heat Exchanger.* A water-to-water heat exchanger can dissipate the expected heat output from the system under all expected test conditions.

8.20. *Humidity Gauge*. Psychrometer or hygrometer for measuring Relative humidity measurement in the lab with an accuracy of 2%, and capable of measuring RH between 5 and 95% RH.

8.21. *Insulated Solid Pack Chimney*. For installation of appliances. Solid-pack insulated chimneys must have a minimum of 2.5 cm (1.0 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).

8.22. *Infra red Thermometer (IR gun).* It must be calibrated annually and must have a tolerance of +/-2˚C.

8.23. *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 ± 1.0 pound (± 0.45 kg) and a readout resolution of ± 0.2 pounds (± 0.1 kg).

8.24. *Resistance Temperature Detector (RTD).* ±0.28°C (±0.5°F) or ±0.5% of the temperature being measured.

8.25. *Test Facility Temperature Monitor*. A thermistor, RTD, Type T-Special thermocouple, or another 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 1.0˚F (± 0.5 ºC) of the expected temperatures.

8.26. *TEOM.* A tapered element oscillating microbalance is an instrument used for real-time detection of aerosol particles by measuring their mass concentration. A Thermo Fisher

Scientific TEOM model 1405-D is used to measure and report continuous particulate matter (PM) measurements in an ASTM E2515-11 dilution tunnel or equivalent dilution method, and operated according to the NYSERDA Dichot TEOM Standard Operating Procedures. For lab air PM measurements, a Thermo Scientific TEOM model 1405 single channel TEOM operated according to the NYSERDA Dichot TEOM Standard Operating Procedures shall be used.

8.27. Water Temperature Difference Measurement. 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 must include the temperature sensor, sensor well arrangement, piping arrangements, lead wire, and measurement/recording system. The response time of the temperature measurement system must be less than half of the time interval at which temperature measurements are recorded.

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

8.29. 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 9 of this method.

9. Calibration, Standardization, and Quality Control

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

9.2. ASTM E2515-11. Perform all calibrations required by Section 8 of ASTM E2515-11.

9.3. Carbon monoxide.

9.3.1. Follow the procedures for calibration and standardization in CSA B415. CO procedures must also include the use of a mid-level gas. The CO measurement device must be calibrated across the entire measurement span, with at least 1 gas equal to 80-100% of the measurement span, one gas equal to 40-60% of the span, and one zero gas. Additionally, if the average measured concentration is less than 10% of the measurement span, a 4th gas between 50% and 500% of the average measured concentration must be used. Alternatively, a dual range analyzer or second CO analyzer may be used, taking care to ensure that the average measured concentration is greater than 10% of the lowest measurement range.

9.3.2. Per CSA B415, before the test begins and again, within 24 hours after the end of the test, introduce the low-, mid-, and high-level calibration gases to perform a calibration check. Calibration shall be performed at the same flow rate used during testing. Wait a sufficient time for each calibration gas to flow through the gas analyzer and obtain a stable reading. Readings should be within 2% of the calibration gas concentration. The analyzers shall have a maximum zero and span drift of 3% full scale over a 24-hour period.

9.4. Calibrations.

9.4.1. Conduct all dilution tunnel checks and calibrations per ASTM E2515-11.

9.4.2. Failed calibration checks related to scales (fuel or appliance), sampling flow meter, pressure transducer, or thermocouples invalidate the test.

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

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

9.7. Humidity Gauge for laboratory RH. Calibrate as per the manufacturer's instructions before the first certification test and semi-annually thereafter.

*9.8. Leak Check*s. Conduct sampling equipment leak check and calibration post-test. Failed leak checks invalidate the test run.

9.9. 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 semi-annually 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 or equivalent) 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 calibration weight value within 0.09 kg (0.20 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, then recalibrate or service scale.

9.10. 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

9.11. TEOM - Flow and Leak checks are done before and after every test run per *NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces*. Additional quality control measures are included in the TEOM Operating Procedure.

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

10. Sampling, Test Specimens, and Test Appliances

10.1. Modifications to ASTM E2515-11 requirements.

10.1.1. Presence of liquid water in the sample acquisition, sample transport or filter portions of the sampling system at any time during the test run invalidates the test run.

10.1.2. Dilution tunnel temperature and relative humidity must be measured and logged near the sample probe to calculate tunnel dewpoint. The location and distance of this measurement to the sample probe must be documented.

10.1.3. For a valid test run, the following conditions must not exceed any of the following conditions for more than five minutes in total:

10.1.3.1. 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 115 ˚F (46.1˚C) for any rolling 10-minute average.

10.1.3.2. Tunnel relative humidity must not exceed 90% based on 10-minute rolling averages derived from 1-minute data, excluding periods when the appliance door is open.

10.1.3.3. The air's dewpoint in the tunnel must be at least at 1.8 °F (1.0 °C) below the filter temperature.

10.1.3.4. A minimum tunnel flow of 600 SCFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3.

10.1.3.5. All exceedances must be reported in the test anomalies section, even if deviations are within test method tolerances.

10.1.4. Particulate Matter Sampling. TEOM data must be collected at 1-minute intervals for reporting. TEOM operation must follow the procedures listed in the most recent TEOM SOP found in the EPA docket at https://www.regulations.gov/docket/EPA-HQ-OAR-2016-0130

10.1.5. TEOM data must be reported in an excel spreadsheet following the minimum data reporting requirements.

10.2. Rounding requirements must confirm to specification and procedures detailed in US EPA TID-024.

10.3. Flue Gas Measurements: CO and CO_2 data shall be reported in 1-minute intervals and gathered following requirements as specified in this test method.

10.4. Particulate Matter Sampling. TEOM data will be collected and reported at 1-minute intervals. TEOM operation shall follow the procedures listed in the TEOM SOP.

10.4.1. Sample Collection. Particulate Matter Sampling uses a 2-channel dichot TEOM to obtain real-time data. TEOM data shall be used to report the first-hour emission rate, to provide data for phased emissions, and real-time data reporting requirements. All measurements shall run through the entirety of the test to obtain full run data.

10.5. CO and CO2 Sampling

10.5.1. Install system as shown in Figure 1.

10.5.2. Install Flue Gas Sample probe 2 in. (50 mm) above the flue gas temperature measurement in the stack per CSA B415.

10.5.3. Setup Flue Gas Measurement System with an appropriate sample flow rate to reach 90% of their final reading within 30 seconds when beginning at ambient levels and responding to a high-level calibration gas per CSA B415.

10.5.4. Flue Gas Measurement System shall record CO and CO_2 concentrations at one minute intervals.

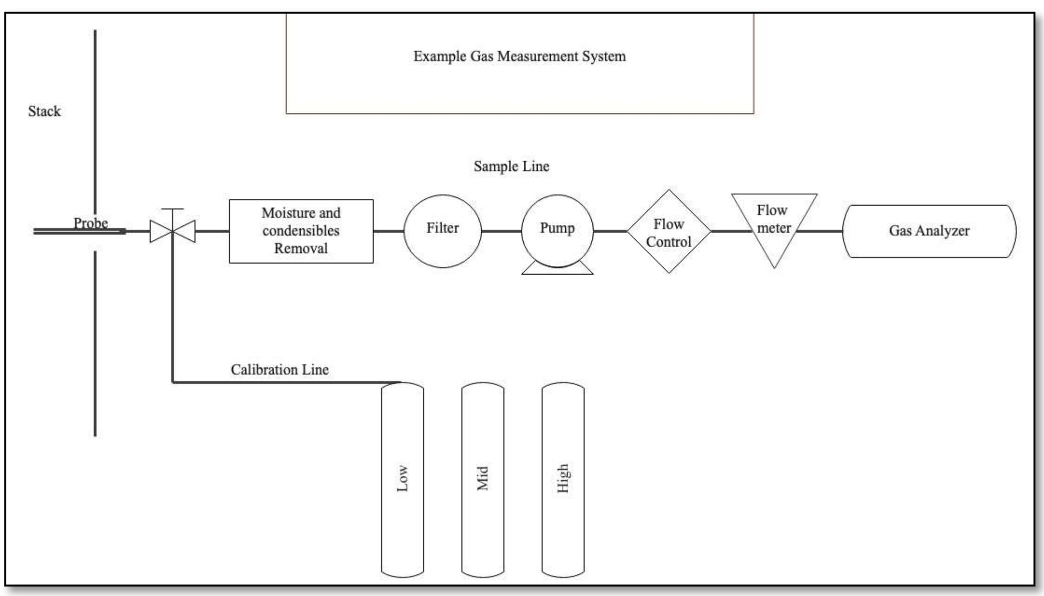

Figure 1. Example of Gas Measurement System

10.6. Test Specimens. Systems (appliance and buffer tank) must be supplied as complete systems, including all controls and accessories necessary for installation at the test facility, including thermal buffer tank description and volume. The manufacturer must 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. A complete set of specifications, designs, and assembly drawings must be provided when the product is placed under the certification of a third-party agency.

10.7. User Guide. The manufacturer must supply a one-page user guide that must 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 must be the only directions provided and used by the testing facility for certification purposes; it must address key user operations for simple baseboard heating and conform to the following requirements. Manufacturers are not allowed to direct or inform any testing portion 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 must conform to the following design specifications:

10.7.1. User Guide elements – The User Guide cannot contradict or deviate from user instructions in the appliance user manual. All elements in the User Guide must be included in the Owner's Manual, and cannot be contradicted in the Owner's Manual. The User Guide must include information on the following items.

10.7.1.1. Appliance preparation – what must be done to the appliance before starting a fire, including appliance setpoints and software settings. Settings must reflect use in high-temperature heating systems.

10.7.1.2. Appliance and buffer (system) settings include modulation, setpoint, restart, operating limits, safety high limit temperatures, and other routine operations (cleaning cycles, etc.).

10.7.1.3. 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 and certification testing.

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

10.8. Preparation of Apparatus

10.8.1. Place the appliance centrally on the platform scale, meeting the requirements detailed in this protocol.

10.8.2. The setup must conform to the schematics in Figures 2 through 5, using the setup appropriate to the tested appliance.

10.8.2.1. The manufacturer may assist or instruct during the appliance installation so long as the installation occurs before the first test run.

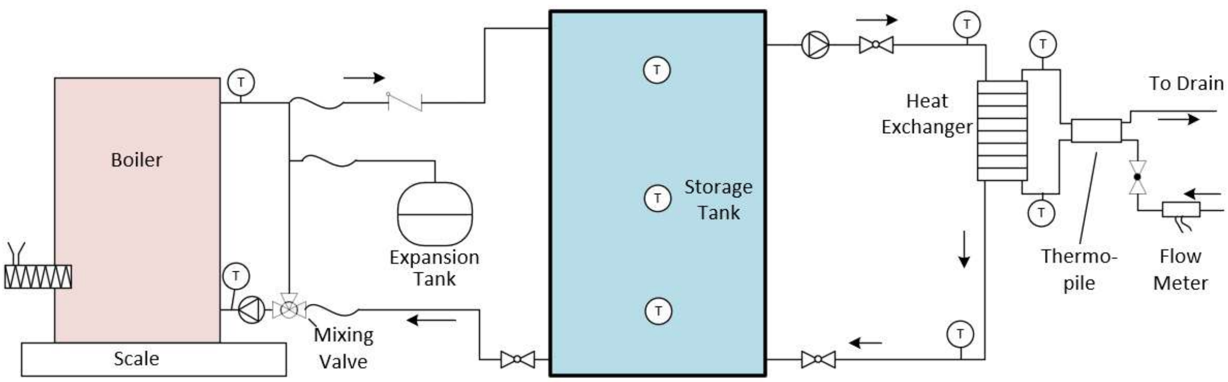

Figure 2. Test Plumbing with 1 buffer

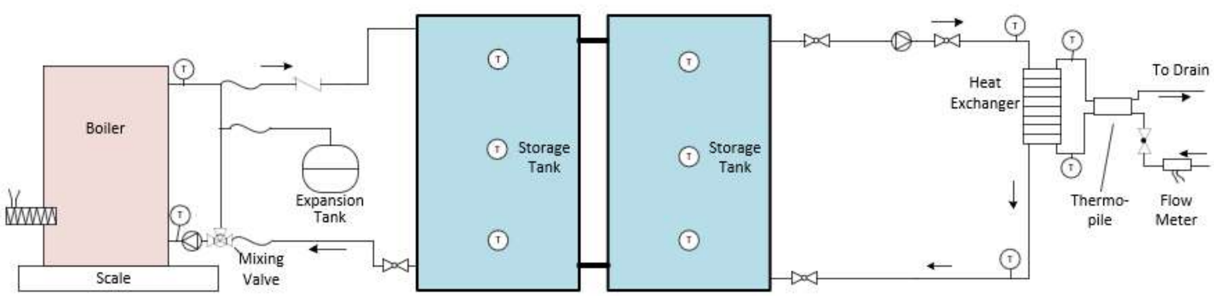

Figure 3. Test plumbing with multiple buffers

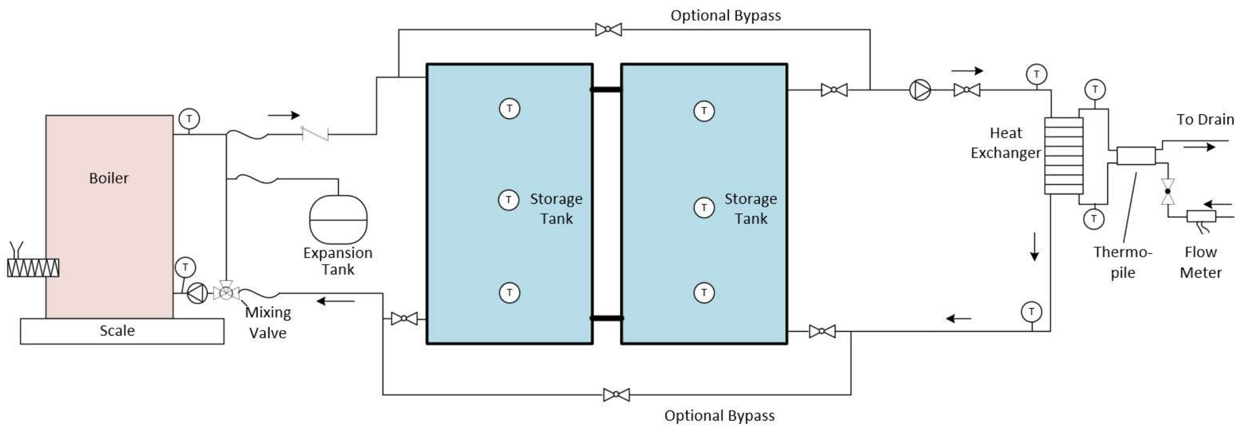

Figure 4. Optional buffer bypass loop for safety

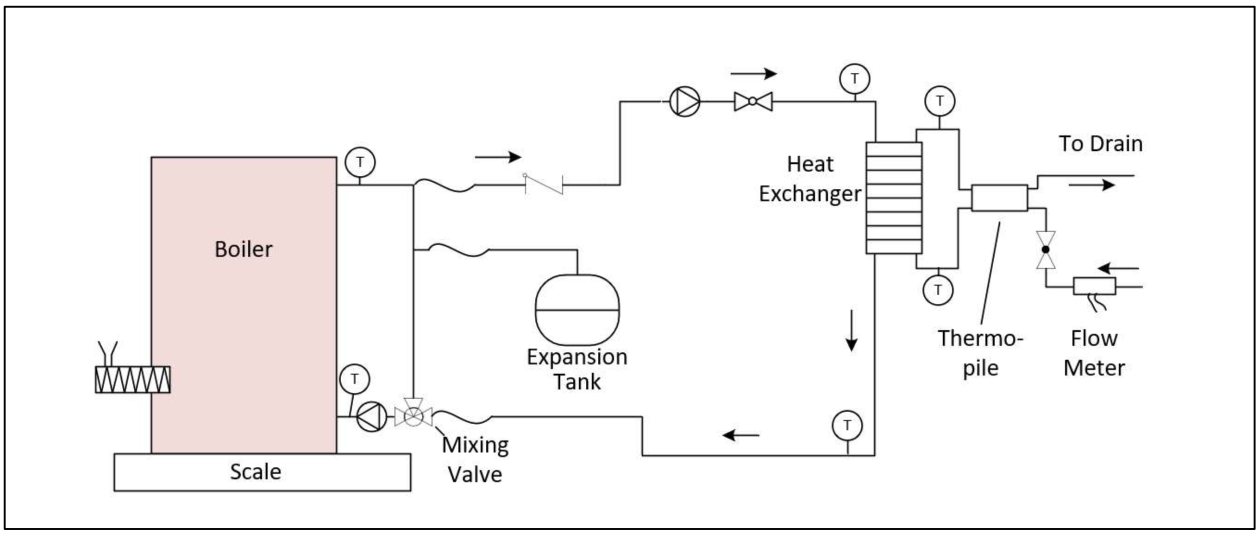

Figure 5. Test Plumbing without buffer tank

10.8.3. 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. The pump must not be installed in such a way as to change or affect the flow rate between the appliance and the heat exchanger. If the manufacturer specifies the use of a recirculation pump, the manufacturer must provide all piping, pumps, and controls necessary for the recirculation system.

10.8.4. 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 must 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.

10.8.5. Starting Weight. Before filling the appliance with water, weigh and record the appliance mass.

10.8.6. Heat Exchanger.

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

10.8.6.2. Locate temperature sensors in a thermowell or direct contact to measure the water temperature, center stream, at the inlet and outlet of the supply side of the heat exchanger, and supply and return side of the hydronic heater. If a direct measurement is not feasible, then use an indirect approach that takes steps to insulate the measurement from the ambient temperature.

10.8.6.3. 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.

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

10.8.7. 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.

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

10.8.9. 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 the air is purged correctly.

10.8.10. Clean the flue with an appropriately sized wire chimney brush before initiating Run 1 of the certification test. Test documentation should include the date and time of the flue cleaning.

11. Appliance Conditioning

11.1. Appliance Aging. Before testing, the appliance must be firing for a minimum of 50 hours. The cooling load should be adjusted to prevent the appliance from cycling off and avoid long periods of idling or standby. At least 20 hours must be spent at the high heat output (defined as 80-100 percent of maximum heat output). The conditioning may occur at the manufacturer's facility before testing or at the certification facility. Conditioning data must include time spent in each heat output mode per the table below.

11.2. If the appliance uses a catalytic combustor, it must be engaged according to the 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.

11.3. Appliance Aging Documentation. The manufacturer of the certified testing laboratory must conduct and document the aging procedure. All aging data must be reported and must 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.

12. Procedure.

12.1. Test Facility Conditions. The test facility must meet the following requirements during testing:

12.1.1. The dilution tunnel must conform to Section 9.7 of ASTM E2515-11

12.1.2. The test facility temperature must be maintained between 55 and 88˚F (12.8 and 31.1 ˚C) during each test run, measured as specified by ASTM E2515-11.

12.1.3. Air velocities within 2.0 ft (0.60 m) of the test appliance and exhaust system must be less than 50 ft/min (0.25 m/sec) without fire in the unit. Confirm before the start of a test run and at the end of the test run.

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

12.2. Test Fuel. This method can be used with wood pellet fuels and wood chip fuels.

12.2.1. Testing must use a PFI-certified premium hardwood blend pellet that contains no softwood with an ash content target of greater than 0.40%.

12.2.2. Fuel Temperature. The test fuel temperature must be between 12.8 to 30.6 °C (55 to 87 °F).

12.2.3. Fuel Analysis – pellet fuel must be analyzed and reported (in the test report) using the following methods:

- Ash: ASTM D1102
- Bulk density: ASTM E873
- Carbon, hydrogen, nitrogen: ISO 16948
- Chlorine: ISO 16994
- Heating value: ISO 18125
- Metals: ISO 16968
- Moisture: ASTM E871
- Sampling: ISO 18135

12.2.4. Wood chip fuels must conform to the following requirements:

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

12.2.4.2. 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.

12.3. Manufacturer participation in certification testing.

12.3.1. A manufacturer representative 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 unless the representative notices improper appliance operation. If the representative notices improper appliance operation, the representative may request halting the certification test. This request must be in written form and documented in the test report. The names of testing witnesses cannot be withheld as confidential business information (CBI).

12.3.2. 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 allows for remote witnessing or recording of the test.

12.4. Appliance Instructions and Program Configuration/Setting.

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

12.4.2. Appliance Operation and Adjustments. If the appliance does not arrive with control settings preset, follow the User Guide instructions for control settings. Adjustments to controls are not allowed once testing has begun. If changes to controls are required due to an invalid test run, then the adjustments must be documented, and the User Guide must be revised to incorporate changes before starting the new test series. The test report must document both User Guides (original and adjusted). The owner's manual may only include operational instructions given to the laboratory for the certification test.

12.4.3. A manufacturer representative may assist with control/appliance settings before the start of the test, but changes must be consistent with the User Guide. Any deviations from the User Guide require a revised User Guide before starting the certification test series. Changes in the User Guide that impact instructions on appliance operation after completing the certification test must invalidate the test series and require a retest of the appliance. Both User Guides must be documented in the test report.

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

12.6. Before each test series, the firebox must be vacuumed. Testing must begin without any ash or other materials in the appliance.

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

12.8. The flow rate of water between the buffer and the load heat exchanger must be set to achieve a return temperature from the heat exchanger back to the system of 140 ˚F (60 ˚C) or greater, which reflects the minimum temperature for high-temperature residential heating systems.

12.9. Low Appliance Temperature. If at any time the return water temperature falls below the appliance minimum operating temperature, as specified by the User Guide, or 140 ˚F (60 ˚C), then stop cooling until the appliance water temperature average reaches the target temperature. All interruptions in heat load must be documented and reported.

12.10. All water temperatures, water flow rates, appliance temperatures, and other temperature sensors must be recorded at intervals of 1 minute, at a minimum.

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

12.12. Scale weight must be recorded at a minimum of 1-minute intervals and documented at the start and end of each test phase.

12.13. PM Sampling and measurements for efficiency and emissions begin when the system is powered on and procedures to ignite the boiler have been initiated.

12.14. Complete Test Requirements. Conduct one appliance heat output assessment test run and three complete and valid IDC Pellet Boiler tests per this protocol.

12.15. Appliance Heat Output Assessment Test Run. This test run aims to identify the maximum heat output rating, which informs the target load for Phase 2, Phase 3, and Phase 6 of the IDC protocol for the appliance.

12.15.1. Phase 1 – run per Section 12.16.1 of this test method.

12.15.2. Phase 2 – *Maximum Heat Load.* This phase commences immediately after Phase 1. Run per Section 12.16.2 of this test method.

12.15.3. End of Appliance Heat Output Assessment Test Run. The test runs ends after the conclusion of Phase 2.

12.15.4. Documentation Requirements - Phase 2

12.15.4.1. Record scale weight at the end of the test run.

12.15.4.2. Provide data and results of the test run.

12.15.4.3. Complete the calculation to determine the maximum and 13% percent heat demand for the IDC Hydronic Heater (HH) test runs.

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

IDC Pellet Hydronic Heater Test Procedure Summary	
Phase 1 – Start-up	Start-up per manufacturer's instructions. Pull off heat as needed when approaching the 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. The unit must complete the rampdown in the time specified by the test protocol as: pump flow (gal/min)/total on board storage (gal). 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.

	Transition Phase - If the hydronic heater is in the middle of an on-cycle after 120 minutes or cycles back on after completing 1 cycle, stop cooling and allow the hydronic heater to heat up and cycle off.
Phase 4 – No load	• No heat load for 45 minutes. • *Transition Phase - At the end of Phase 4, set the cooling load as high as 120% until the hydronic heater cycles on before Phase 5.*

Phase 5 – Cyclic operations	• Forced cycling - Must complete 1-6 cycles, as determined by cycling time in Phase 2.
	• A cycle consists of one on-period and one off-period.
	  o During on-cycle - cooling water is stopped, and the system heats to the system operating limit temperature.
	  o Off-cycle - Wait 30 minutes, then set cooling water at 100% heat load at the load heat exchanger until the system reaches the system restart temperature.
	• Phase 5 begins during the "on period" of the cycle
	• Phase 5 ends the last off period has been completed.

Phase 6 – Recovery	• Phase 6 begins immediately after Phase 5 ends. • 100% heat load for 60 minutes.

12.16.1. Phase – Start-up.

12.16.1.1. *Appliance Parameters.*

12.16.1.1.1. Tare the appliance scale before starting the test. Record appliance scale weights at the start and end of Phase 1.

12.16.1.1.2. Appliance temperature. For the first run (Run #1), measure and record appliance temperature (primary and secondary combustion chambers) and firebox temperature using an IR gun or handheld temperature sensor. Reporting must include:

12.16.1.1.2.1. Temperature sensor measurements must be held for one minute and measure a single point on each wall. Four walls must be measured.

12.16.1.1.2.2. Appliance exterior, stack, and internal firebox temperatures must be measured 30 minutes before starting any test run and reported for all test runs.

12.16.1.1.2.3. Appliance temperatures: internal (primary and secondary combustion chamber) and external temperature must not be greater than the ambient temperature or water jacket temperature, whichever is higher (+/- 15 ˚F (9 ˚C)) for Run 1. If the temperature exceeds +/- 15 ˚F, the report must contain an explanation for the deviation. If Run 1 is invalid or incomplete, the appliance must meet Run 1 conditions for at least one valid run. There is no appliance starting temperature requirement for Runs 2 and 3 except in the case of a failed first run.

12.16.1.1.3. Water temperature requirements.

12.16.1.1.3.1. *No external thermal storage/buffer tank:* Average hydronic heater temperature must not exceed 120 ˚F (48.9 ˚C) at the start of any test run. The average starting temperature must be included in the test report.

12.16.1.1.3.2. *Units with external thermal or buffer tank:* Buffer tank and/or thermal storage must 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 must be reported in the test report.

12.16.1.2. *Appliance Operation during Phase 1.*

12.16.1.2.1. Following the start-up of the appliance, slowly adjust the cooling water to achieve high load operations. If the return water temperature appliance drops below minimum operating temperatures after reaching them, heat demand must be adjusted.

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

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

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

12.16.2.1. *Appliance Parameters Phase 2.* During Phase 2, the unit must produce an average heat load output rate that is within ±10% of the maximum heat load produced during the appliance heat output assessment test run, as defined by Section 12.15.2 of this test method, which shall be reported as the maximum heat output capacity of the appliance.

12.16.2.2. *Appliance Operation during Phase 2.*

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

12.16.2.2.1.1. If the appliance temperature rises and approaches the operating limit at any time, the heat load must be increased to prevent the appliance from cycling off or modulating to a lower firing rate.

12.16.2.2.1.2. If, at any time, the appliance or buffer temperature fluctuates more than 5 ˚F, adjust the cooling load to decrease or increase heat demand until the appliance or buffer temperature is within 5 ˚F of Phase 2 starting temperatures.

12.16.2.3. *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. Record the heat demand at least once per minute and maintain a running average of these one-minute values.

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

12.16.3.1. *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.

12.16.3.1.1. Ramp down. The appliance ramp down is part of phase 3. Ramp down is the time it takes for the appliance to go from 100% to 13% heat demand. The amount of time spent in ramp down is based on the amount of water (gallons) in the onboard system divided by the pump exchange rate (gallons per minute). The test report must indicate the time period used for ramp down.

12.16.3.1.2. 13% heat demand. The appliance stays at this heat load for 120 minutes or one complete cycle, whichever comes first.

12.16.3.1.3. Heat load on the system at the load heat exchanger is placed at 13% +/- 2% of maximum heat load output as defined by calculations completed in Section 12.15.4.3 of this test method.

12.16.3.2. *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.

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

12.16.3.2.1.1. If the unit begins to cycle off within 0-30 minutes of Phase 2, 6 cycles must be completed in Phase 5.

12.16.3.2.1.2. If the unit begins to cycle off within 31-60 minutes of Phase 2, 4 cycles must be completed in Phase 5.

12.16.3.2.1.3. If the unit cycles off within 61-90 minutes of Phase 2, 3 cycles must be completed in Phase 5.

12.16.3.2.1.4. If the unit cycles off within 91-120 minutes of Phase 2, 2 cycles must be completed in Phase 5. If the unit does not cycle during Phase 2, only 1 cycle must be completed in Phase 5.

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

12.16.4.1. *Appliance Operation during Phase 4.* The appliance heat load is 0%, and the appliance is turned off. The appliance stays at this 0% heat load for 45 minutes. Ramp down to this heat load must be made in a period of fewer than 5 minutes or as quickly as automated controls allow. The test report must provide the time period used for ramp down.

12.16.4.2. *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 set point where the appliance will cycle on at the beginning of Phase 5. This may be completed by manually setting a cooling load. The cooling load must 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.

12.16.5. Phase 5 – Cyclic Operations

12.16.5.1. *Appliance Operation during Phase 5.* This phase emulates the appliance's operation, responding to a thermostat call at the start of this phase, and powering 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.

12.16.5.2. During Phase 5, the unit must complete the number of cycles as determined in Phase 2, as defined in Section 12.16.3.2.1 of this test method.

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

12.16.5.2.2. If the appliance shuts down on the high-temperature safety control during this test, requiring a manual reset, the test is ended, and all data must be saved and included in the test report as an incomplete test run. A new test run must be completed to replace this incomplete test run.

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

12.16.6. Phase 6 – Response to Setback Conditions.

12.16.6.1. *Appliance Operation during Phase 6.* For 60 minutes, the cooling water must deliver a heat load of 100% of the nominal full-load output, as defined by Section 12.15 of this test method. If the return water temperature in the system (heater and/or buffer tank) drops below the 140 ˚F (60 ˚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 must be recorded.

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

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

12.16.7.1. *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.

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

12.17.1. Appliance Heat Output Assessment Run – The unit cannot run for a period greater than 8 hours within the 48 hours before starting official test runs. Record the average firebox temperature within 1 hour of the start of the test by measuring the central point along all walls of the firebox.

12.17.2. IDC Run 1 – The unit cannot run for a period greater than 8 hours within the 48 hours before starting official test runs. Record the average firebox temperature within 1 hour of the start of the test by measuring the central point along all walls of the firebox.

12.17.3. IDC Run 2 – The unit must 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.

12.17.4. IDC Run 3 – The unit must wait a minimum of 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.

12.18. Test Series Completion. A complete test series is defined as the successful completion of one valid appliance heat output assessment test run, as defined in Section 12.26 of this test method, and three valid test runs, completing all 6 phases of the IDC test run as defined by Section 12.27 of this test method. Once three valid IDC runs have been completed, the testing is complete. No additional runs may be completed.

12.19. Additional Test Runs. If there is an invalid or incomplete test run, another additional test run may be attempted to complete the test. The measurement data and results of all test runs (valid, invalid, and incomplete) 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. A maximum of five runs attempts can be completed. If an appliance cannot complete three valid runs after five attempts, the appliance has failed the certification test.

12.20. Failure to Operate at All Test Conditions. If the appliance fails two runs due to incomplete or invalid test runs, it shall be determined that the appliance has failed the certification test and requires a modification to appliance design. Incomplete failed test runs are defined as the following:

12.20.1. If an appliance fails to complete all six phases of the test run, the run shall be considered an incomplete test run.

12.20.2. 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 an incomplete run.

12.20.3. After the second incomplete test run, the lab must verify that all appliance settings and operations are correct and consistent with manufacturer-supplied information.

12.20.4. After three incomplete test runs, the unit is deemed to have failed the test, and the unit cannot be certified with this test method.

12.20.5. If a test run violates the test method parameters, the run is invalid.

12.20.6. System failure.

12.20.6.1. If, during certification testing, a critical component of the appliances or necessary plumbing is damaged or breaks, the certification test will stop and is defined as an aborted test run. Aborted test runs are not included in the maximum of five runs requirements detailed in Section 12.16 of this test method.

12.20.6.2. If damage is noted during a test, repairs shall be made by the manufacturer (or by laboratory personnel with written direction from the manufacturer). If the repair involves components that require conditioning, the appliance shall undergo another round of wood heater conditioning, as specified in Section 11 of this test method. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The conditioning process is intended not only to 'cure' the appliance but also to cycle parts that may fail with extended use. Alternate aging techniques may be approved by the administrator, depending on the nature of the failure, material, and critical nature.

12.21. PM Data Recording.

12.21.1. All TEOM data shall be collected and recorded at intervals of 1 minute. TEOM operation shall follow the procedures listed in *NYSERDA Standard Operation Procedures for use of a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces.*

12.21.2. Tunnel and lab air PM TEOM Data shall be reported using the Excel data analysis spreadsheet templates that are part of the *NYSERDA Standard Operation Procedures for use of a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces*. These data analysis spreadsheets shall be submitted as part of the test report.

12.21.3. Lab PM measurement - TEOM. A single channel TEOM shall be used to measure ambient lab air PM during the test, as configured in *NYSERDA Standard Operation Procedures for use of a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces*. The sample flow shall be 3 LPM.

12.22. CO and CO_2 Data Recording. All CO and CO_2 data shall be collected and recorded at intervals of 1 minute using a continuous sampling approach and applying requirements as specified.

12.23. Scale Measurements shall be recorded at intervals of 1 minute.

13. Calculation of Results

NOTE: For proportioning 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 emission rate in grams per hour for Phase 2.

13.1. Emission Calculations. Particulate matter, carbon dioxide, and carbon monoxide must be calculated using the following methodology and reported as per the data tables in Section 14.

13.2. Particulate Matter Emissions Rates. After the test is completed, determine the particulate matter emissions rate E_r at 1-minute intervals following *NYSERDA Standard Operation Procedures for use of a Thermo Scientific 1405-D TEOM™ in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces* and Section 13.7 of this test method.

13.3. Nomenclature.

BR – average dry fuel burn rate, lb./min

C – Carbon content of dry fuel (wt%)

C_CO – heat capacity of CO at the average stack and room temperatures

C_CO2 – heat capacity of CO_2 at the average stack and room temperatures

C_H2O – heat capacity of water vapor at the average stack and room temperatures

C_O2 – heat capacity of O_2 at the average stack and room temperatures

C_N2 – heat capacity of N_2 at the average stack and room temperatures

H – Hydrogen content of dry fuel (wt%)

O – Oxygen content of dry fuel (wt%)

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 TEOM SOP.

$E_{T(x)}$ = Total PM emissions per phase. (E.g. $E_{T(p1)}$, $E_{T(p2)}$, $E_{T(p3)}$..)

$E_{g/MJ}$ – PM emission factor in grams per megajoule of heat output , g/MJ

$E_{g/MJ(x)}$ – PM emission factor in grams per megajoule of heat output per phase, g/MJ ((E.g. $E_{g/MJ((p1)}$, $E_{g/MJ((p2)}$, $E_{g/MJ((p3)}$..)

$E_{lb./MMBtu\ output}$ – PM emission factor in pounds per million Btu of heat output, lb./MMBtu.

$E_{lb./MMBtu\ output\ (x)}$– PM emission factor in pounds per million Btu of heat output per phase, lb./MMBtu. (E.g. $E_{lb./MMBtu\ output\ (p1)}$, $E_{lb./MMBtu\ output\ (p2)}$, $E_{lb./MMBtu\ output\ (p3)}$)

$E_{g/kg}$ – PM emission factor in grams per kilogram of dry fuel burned , g/kg

$E_{g/kg(x)}$ – PM emission factor in grams per kilogram of dry fuel burned per phase, g/kg ((E.g. $E_{g/kg\ (p1)}$, $E_{g/kg\ (p2)}$, E $E_{g/kg\ (p3)}$..)

$E_{g/hr}$ – PM emission rate in grams per hour, g/hr.

$E_{g/hr(x)}$ – PM emission rate in grams per hour per phase, g/hr. ((E.g.$E_{g/hr\ (p1)}$, $E_{g/hr\ (p2)}$, $E_{g/hr\ (p3)..}$)

E_{Rco} – CO emission rate, g/hr.

HHV – Higher heating value of fuel = Use accredited test results

$_{i}$ – interval

L_{CO} – Heat loss due to CO, %

L_{lat} – Latent heat loss, %

L_{Sens} – Sensible heat loss, %

LHWV- Latent heat of water vapor in 43969 kJ/kgmol

M − Mass flow rate of water in lb./min (kg/min)

MC_i – Average moisture content as determined by ultimate/proximate analysis

MC_a – mass of moisture per unit mass of dry air (humidity ratio at lab ambient conditions)

$CO2_{\%}$– average CO_2 in the dry flue gas (volume %)

CO_{ppm} – CO in the dry flue gas (volume ppm)

$CO_{\%}$ – CO in the dry flue gas (volume %)

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

$Q_{std(w)}$ – Average wet gas flow rate in the dilution tunnel, dscfmw

SC – decrease in scale mass reading during measurement interval, lb.

ti − Data sampling interval, min.

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)
TISavg − Average temperature of the 3 buffer tank sensors at the start of the test, ˚F (˚C).
TFSavg − Average temperature of the 3 buffer tank sensors at the end of the test, ˚F (˚C).
T_S – Flue Gas Temperature, F (C)
$T_{S(K)}$ – Flue Gas Temperature expressed in degrees Kelvin, K
T_r – Room Temperature, F (C)
$T_{r(K)}$ – Room Temperature expressed in degrees Kelvin, K
V_{blr} – appliance water capacity, gallons
V_i – Volume of water indicated by a totalizing flow meter 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} –Weight of fuel consumed 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
η_{SLM} - Stack Loss Method Efficiency, %
Θ – Total length of test run in hours
$\Theta_{(x)}$ – Total length of test run in hours per phase, X

13.4. Determine Heat Input.

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

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

$Q_{inPhaseX} = (W_{fuelPhaseX}/(1+(MCi/100))) \times HHV$, BTU

13.5. 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} = Σ[Cpi ·Δ Ti · Mi · ti] + (Wapp · Csteel + Wwater · Cpa) · (TFavg – TIavg) + (WStorageTank · Csteel + WWaterStorage · Cpa) · (TFSavg – TISavg) 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.

σi = (62.56 + (-0.0003413 x T3i) + (-0.00006225 x T3i 2)) 0.1337, lbs./gal
Cp = 1.0014 + (-0.000003485 x T3i) Btu/lb., ºF
Csteel = 0.1 Btu/lb., ºF
Cpa = 1.0014 + (-0.000003485 X (TIavg +TFavg)/2), Btu/lb., ºF

13.5.1. Determine total heat output rate as:

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

13.5.2. Determine heat load rate as:

Heat load rate = Σ[Cpi ·Δ Ti · Mi · ti]/ Θ
Phase X Heat load rate: $\Sigma_{(PhaseX)}$[Cpi ·Δ Ti · Mi · ti]/ $\Theta_{(x)}$

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

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

13.7. Determine PM emission rates and emission factors as:

$E_{g/hr}$ = 0.000001699 * (Tunnel $Q_{std(w)}$) * (net TEOM PM concentration in μg/m^3), g/hr.
$Q_{std(w)}$ = Determined using ASTM E2515, Equations 3 (without subtracting out moisture of gas stream), 5, 9, and 10.
$E_T = E_{g/hr} \times \Theta$, g

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

$E_{lb./MM\ BTU\ output} = (E_T/453.59)/(Q_{output} \times 10^{-6})$, lb./MMBtu Out
$E_{g/kg} = E_T/(W_{fuel}/(1+MCi/100))$, g/dry kg

For phase calculations, determine $E_{T(x)}$, $E_{g/hr\ (x)}$, $E_{lb./MM\ BTU\ output\ (x)}$, $E_{g/kg\ (x)}$

13.8. Determination of CO Emissions Per Phase and Full Run.

In this section, the CO emission rate and CO emission factor are calculated for each phase in 1-minute intervals. 1-minute burn rate values are determined by calculating a centered 11-minute rolling average based using the information within individual phases only, and flue CO and CO_2 averaged over 1-minute intervals. Calculating CO emission rate/factors for each Phase or the entire run is a simple average of all of the 1-minute intervals over the Phase or the total run.

13.8.1. Determination of Dry Fuel Burn Rate

This section provides a method to determine burn rate each minute by phase or for the entire test run. This considers the reduction in indicated scale mass and the change in boiler water density during the minute.

For each target time point in a Phase or Test Run, the density of water at the start and end of each 1-minute interval must be calculated using the equation in section 13.5 based on the average water temperature of the appliance. Burn rate is then calculated using:

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

This burn rate is calculated for each minute in the Phase. Due to scale resolution and burner operations, the indicated change in scale mass on a minute-by-minute basis is typically not smooth. For this reason, the average burn rate over a longer time is determined and assigned to the target time point. A centered running average approach is used.

For time points in the center part of a phase (more than 5 minutes from the start or end of the Phase), the burn rate for a time period 5 minutes before and 5 minutes after the target time point are averaged to calculate the one minute scale change at the target time point.

For target time points less than 5 minutes from the start of a Phase, the burn rate at the target time point shall be the average of the determined burn rate from the first point of the Phase to the time point 5 minutes after the target time point.

For target time points less than 5 minutes from the end of a Phase, the burn rate at the target time point shall be the average of the determined burn rate from the time point 5 minutes prior to the target time point to the last time point in the Phase.

13.8.2. Fuel.

The following parameters are a function only of the fuel analysis and do not change with flue gas composition:

x= C/12

y = H

z = O/16

13.8.3. Molar Balance Equations.

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

gamma_n = x + y/4 -z/2

beta_n = ((100 * x * CO_{ppm})/(1000000 * $CO2_{\%}$+100 *CO_{ppm}))

alpha_n = ((100 * (x-beta_n)/$CO2_{\%}$)-x-(beta_n/2)-gamma_n * 3.76)/(gamma_n * 4.76)

kmoles of CO produced when 100 kg dry fuel is burned:

MFCO_n = beta_n

kmoles of CO_2 produced when 100 kg dry fuel is burned:

MFCO2_n = x-beta_n

kmoles of O_2 produced when 100 kg dry fuel is burned:

MFO2x_n = (alpha_n * gamma_n+beta_n/2)

kmoles of N_2 produced when 100 kg dry fuel is burned:

MFNI_n = (1+alpha_n) * gamma_n * 3.76

Kmoles of H_2O produced when 100 kg fuel is burned:

MH2O = y/2+MCi/18+MC_a * (((1+alpha_n)*gamma_n*(32+3.76*28))/18)

Total kmols of dry gas produced per 100 kg of dry fuel burned:
DryGas = MFCO_n + MF_CO2_n + MF_O2_n + MFNI_n

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

13.8.4 Calculation of CO Emission Rate and CO Emission Factor.

For each interval during which the burn rate is not zero, calculate the CO emission rate and emission factor as follows:

CO emission rate, g/hr
ERco = (CO_{ppm} * DryGasRate * 28 * 454)/(1000000 * 0.454)

CO emission factor, g/kg dry fuel

EIco = (DryGas * CO_{ppm}* 1000 * 28)/(100 * 1000000)

13.9. Stack Loss Method Efficiency for Quality Control Check.
This section calculates the average stack loss method efficiency for each of the 6 phases. For each Phase, the stack loss method for each minute is combined with the burn rate for each minute to yield a burn rate weighted average stack loss method efficiency. The calculations in Sections 13.9.2 through 13.9.5 shall be done for each 1-minute interval during each Phase.

13.9.1. Molar Balance Equations.

Parameters and equations in Sections 13.8.2 and 13.8.3 are used in the following sections.

13.9.2. Heat Capacity of Exhaust Products

The general equation for representing how the heat capacity of the exhaust products varies with temperature is:

C=*A*TK+B*

Where:

C = heat capacity J/mol K or kJ/kgmol K

A and B are constants

TK = $T_{s(K)}$ or $T_{r(K)}$

The values for A and B for the exhaust components are provided in the table below.[1]

Component	A	B
CO	0.0026	28.42
CO2	0.031	28.55
H2O	0.0083	31.32
O2	0.0089	26.72
N2	0.0037	27.94

For each component, heat capacity is calculated for each minute at the stack temperature and at room temperature ($T_{s(K)}$ and $T_{r(K)}$). The average of these is used to calculate sensible heat loss below.

13.9.3. Calculation of Heat Losses for Efficiency Determination.

Higher heating value in kJ/kg (conversion from Btu/lb)

HHVJ=HHV*2.326

Heat loss in latent heat of water vapor, % of input energy

L_{lat}=MFH20*LHWV/HHVJ

[1] Heat capacity data has been obtained from: E.W. Lemmon, M.O. McLinden and D.G. Friend, "Thermophysical Properties of Fluid Systems" in NIST Chemistry Web Book, NIST Standard Reference Database Number 69, Eds. P.J. Linstron and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg, MD, 20899, https://doi.org/10.18434/T4D303, (retrieved November 4, 2018).

Heat loss in chemical energy in CO, % of input energy

L_{co}=MFCO*282993/HHVJ

Heat loss in sensible heat in flue gas, % of input energy

L_{sens}=(MFCO*C_CO+MFCO2*C_CO2+MFH20*C_H20+MFO2*C_O2+MFN2*C_N2)*($T_{s(K)}$-$T_{r(K)}$)/HHVJ

13.9.4. Calculation of Stack Loss Method Efficiency for Each Minute.

Stack loss efficiency, %

$\eta_{SLM} = 100-L_{lat}-L_{co}-L_{sens}$

13.9.5. Calculation of Run Stack Loss Method Efficiency.

Run Stack Loss Efficiency = Burn rate-weighted average of all of the one minute calculated Stack Loss Method Efficiencies η_{SLM}

Note that negative burn rates are set to 0.

14. Reporting Requirements. The report must include the following:

14.1. Introduction – no portion of the introduction may be claimed as CBI.

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

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

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

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

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

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

14.2. Summary and Discussion of Results – no portion of the introduction may be claimed as CBI.

14.2.1. Record summary results in tables 1A, 1B, and 1C. Table of results to include test run number, the average burn rate for the entire run, particulate emission rate for the full run, particulate emission rate for start-up, carbon monoxide emission rate for an entire run, carbon monoxide for start-up, efficiency, burn time – total and for phase 2, 3, and 6.

14.2.2. The report must contain the following:

For each test run, calculate PM ER data for the six individual phases. Calculated results for the emissions are reported as total emissions in grams, grams per hour, and grams per kilogram.

14.2.3. Provide a plot of PM emission rate in grams/hour vs. time, based on 1-minute TEOM data for the entire test period for each run. The report must include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

14.2.4. Summary of other data – test facility conditions such as test facility temperature, air velocity and humidity, catalyst averages, pre-test fuel weights, test fuel charge weights – total.

14.3. Discussion – no portion of the discussion may be claimed as CBI.

14.3.1. Discussion must include detailed information describing each test conducted on the appliance:

14.3.1.1. How the test was run.

14.3.1.2. Specific test run problems and solutions.

14.3.1.3. Test run result.

14.3.1.4. Deviations.

14.4. Process description:

14.4.1. 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 must be included.

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

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

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

14.4.2.3. Provide data on sampling blanks.

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

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

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

14.5.2. Test method quality control procedures to include leak-checks.

14.5.3. Delivered efficiency shall be compared to stack loss efficiency. If Delivered

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

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

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

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

14.6.4. 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).

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

14.6.6. 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 must be provided along with an analysis as to why these elements had no impact.

14.6.7. All required data and applicable blanks for each test run must 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 must be accessible for review.

14.6.8. For each test run: report TEOM flow and temperature and verification of all TEOM parameters presented in the TEOM SOP.

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

14.8. Complete data tables below.

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 Dur.	Wood Cons.	Total Heat Output	Total Heat Input	Stack Loss Eff	Del. Eff	CO Rate
	Btu/hr	Btu/hr	min	Lb.	Btu	Btu	%	%	g/min
1							n/a	n/a	
2							n/a	n/a	
3							n/a	n/a	

4							n/a	n/a	
5							n/a	n/a	
6							n/a	n/a	
Total									

Data Summary Part A - Run 2

Phase	Target Load	Actual Load	Phase Dur.	Wood Cons.	Total Heat Output	Total Heat Input	Stack Loss Eff	Del. Eff	CO Rate
	Btu/hr	Btu/hr	min	Lb.	Btu	Btu	%	%	g/min
1							n/a	n/a	
2							n/a	n/a	
3							n/a	n/a	
4							n/a	n/a	
5							n/a	n/a	
6							n/a	n/a	
Total									

Data Summary Part A - Run 3

Phase	Target Load	Actual Load	Phase Dur.	Wood Cons.	Total Heat Output	Total Heat Input	Stack Loss Eff	Del. Eff	CO Rate
	Btu/hr	Btu/hr	min	Lb.	Btu	Btu	%	%	g/min
1							n/a	n/a	
2							n/a	n/a	
3							n/a	n/a	
4							n/a	n/a	
5							n/a	n/a	
6							n/a	n/a	
Total									

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

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_i	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.	Hr	lb.	%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./M MBtu Out	g/MJ	g/hr	g/kg fuel	g/hr	g/kg fuel
1								
2								
3								
Average								