NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves Using Cordwood: Measurement of Particulate Matter (PM) and Carbon Monoxide (CO) Emissions and Heating Efficiency

Note: This method does not include all the specifications (e.g. equipment and supplies) and procedures (e.g., sample and analytical) essential to its performance. Some material is incorporated by reference from other methods. Therefore, to obtain reliable results, persons using this method 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 5G – Determination of Particulate Matter from Wood Heaters
- Method 10 - Carbon Monoxide - Instrumental Analyzer

1. Scope and Application

1.1. This test method specifies operation and fueling for certification and auditing of manually operated wood-fired stoves and heaters with manual or automatic controls and single burn rate cordwood stoves.

1.2. This test method measures particulate matter (PM) emissions, carbon monoxide (CO), carbon dioxide (CO_2), and efficiency.

1.3. Stack draft measurements

1.4. Particulate emissions are measured in a dilution tunnel.

1.4.1. As specified in Method 5G-X PM

1.4.2. Using Method 5G-X PM for manual filter PM measurements

1.4.3. Using the most recent version 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 with calculations for grams PM emitted”.

1.5. Carbon monoxide using modified EPA Method 10.

1.6. Carbon dioxide and oxygen using modified EPA Method 3A.

1.7. Efficiency using calculations contained within this test method

1.7.1. Efficiency calculated using data from L2, L3, and L4.

1.7.2. All test run data must be used. For efficiency calculations, no outside or additional testing data is allowed.

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

1.9. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. The test quantifies PM and CO emissions and provides overall efficiency ratings, maximum burn time, and heat output.

1.10. Data Quality Objectives. Adherence to the requirements of this method will enhance the quality of the data obtained from air pollutant sampling methods.

1.11. Distinguishing features of appliances covered by this standard include:

1.11.1. Cordwood fuel is hand-fed into a firebox.

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

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

1.13. Data Quality Objectives.

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

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

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

2. Referenced Methods

2.1. EPA GD-31 Technical Assistance Monograph Evaluation Procedure for Multi-hole Sample Probes available at: https://www.epa.gov/sites/default/files/2020-08/documents/gd-031.pdf

2.2. "NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel with wood-fired stoves, hydronic heaters, and furnaces with calculations for grams PM emitted".

2.3. Method 5G-X.

2.4. OTM for EPA Method 3A.

2.5. OTM for EPA Method 10.

3. Definitions

3.1. Aborted Test Run – The run must be considered aborted if a force majeure event occurs, such as a power outage or equipment operation failure.

3.2. Active Appliance Test Documentation – the active period of a test is defined as the following events: (1) Door opening and closing, damper adjustments, adjustments of air controls, (2) Kindling and start-up wood within the stove and prior to ignition; (3) Coal bed raking, (4) Fuel pieces before loading; (5) Fuel in firebox immediately after loading, (6) Fuel adjustments; (7) End of the test run coal bed conditions (this requires opening the door at the end of test), or (8) any other event where the user engages with the appliance.

3.3. Alternative low setting - The manufacturer may identify an alternative low setting for the test series. The same low setting must be used for all portions of the test series. This setting must be used whenever the test method calls for a low air setting. No other setting may be used. If the test series uses an alternative low setting, the setting must be permanently marked on the stove before testing and must achieve a burn rate of 1.1 dry kg/hr or less during the L4 phase for test runs 2 and 3. There is no burn rate requirement for the test run when the stove has been vacuumed before the test run.

3.4. Appliance – a wood heater capable of and intended for space heating defined in the applicable regulation. The appliance includes a combustion chamber, combustion air settings, operating controls, and a thermostat if specified, and any other accessory required for standard operation, such as a barometric damper,

3.5. Automatically controlled appliance – an appliance whose air controls are controlled automatically controlled throughout the appliance operation and can only be disabled by a technician or when in a power-out mode. Appliances controlling air for portions of a burn cycle are not automatically controlled appliances for this test method.

3.6. Catch - Net mass deposited on the sample filters.

3.7. Centroidal Area – means the central area of the stack or duct that is within 1 inch of the stack or duct center line. This area has the same geometric shape as the stack or duct.

3.8. Certification or audit test – a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in this protocol.

3.9. Chop – using a piece of wood (no poker or other equipment allowed) to strike a piece of the fuel charge to break it into smaller pieces, chopping at most 4 times during a loading event.

3.10. Coal-bed Stirring – using a piece of wood or other equipment to stir the coal bed of the appliance. Coal bed stirring is not allowed during IDC test runs.

3.11. Coal-bed Leveling – using a piece of wood in the fuel charge to level the coal bed. No special formations can be made, such as creating coal bed formations, pushing the coals to one side or creating slopes or troughs with the coals for a valid IDC test run.

3.12. Data recorder – The equipment that permanently records the concentrations reported by the analyzers or other measurement systems.

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

3.14. East-west stove – a stove where the firebox dimension parallel to the loading door is greater or equal to the stove depth measurement. Logs are loaded so that they are viewed on the long length of the stove.

3.15. Emission factor – the emission of a pollutant expressed in mass emitted per mass of wood burned from the appliance, typically reported as grams per kilogram.

3.16. Firebox – the portion of the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.17. Firebox depth – the horizontal length of the fire chamber dimension measured perpendicularly to the loading door. The firebox depth measurement is from the furthest point on the back of the firebox to the inner surface of the loading door (glass or steel door front). The longest actual firebox depth measurement must be input into the fuel loading calculator.

3.18. Firebox height – the vertical distance from the floor of the firebox to the bottom of the baffle. If no baffle exists, the firebox height is the longest point where fuel may loaded must be input into the IDC Cordwood Stove Fueling Calculator.

3.19. Firebox width – the horizontal fire chamber dimension that is parallel to the loading door. The longest length from side to side must be input into the fuel calculator. For trapezoidal units, the manufacturer must report the largest and smallest width in the report but may use the average of the largest and smallest dimension for determining fuel length in the fuel calculator.

3.20. Firebox volume, usable – the calculated volume of the firebox, using the IDC Fuel Calculator for Cordwood Stove Testing.

3.21. Flue Gas Measurement System – All the equipment used to measure stack gas components of interest. This system comprises five major subsystems: sample acquisition, sample transport, sample conditioning, gas analyzer, and data recorder.

3.22. Fuel Adjustment – manipulations to the fuel charge to reflect typical owner practices that allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment includes minor changes in fuel placement. It does not include chopping the wood, stirring the coal bed, or reorganizing fuel placement.

3.23. Fuel load calculator – The Excel spreadsheet tool that determines the allowable test fuel load weights and required piece sizes for each individual load.

3.24. Fuel loading direction – For loads 3 and 4 fuel must be loaded parallel to the dimension with the largest value. A crisscross configuration is allowed for L1 and L2 but cannot be used as a load configuration for loads L3 or L4.

3.25. Full firebox measurement – the actual measurements of the firebox without any subtractions, showing all measurements within a detailed schematic.

3.26. Gas analyzer – Instrument that measures and transmits an output proportional to a gas concentration.

3.27. High air setting — For purposes of this test method, the highest air setting on the stove is the setting with the highest (maximum) air flow for the appliance. All settings must be set for maximum air flow.

3.28. IDC User Guide – the IDC user guide provides a template for manufacturers to provide information on elements that require direction from the manufacturer to run the IDC test protocol. The manufacturer may only specify elements in the User Guide. The manufacturer cannot specify alternative operational protocols from those contained in this test method.

3.29. Incomplete Test Run – Any test run that does not successfully complete all the test phases as detailed in this test method continuously due to stopped fuel combustion or other appliance issues.

3.30. Invalid Test Run – When an appliance does not successfully complete all operational elements of the test protocols to include following test method procedures, calibrations, QA/QC, checks, etc. as detailed in this test method.

3.31. Kindling pieces – small pieces of wood less than 1" in diameter. There are no bark or moisture requirements for these pieces, however kindling pieces must not be dried or stored anywhere but in laboratory ambient conditions. Kindling length may be 50 – 100% of the test fuel length. Individual kindling pieces may weigh no less than 1.5 ounces.

3.32. Large fuel pieces – pieces that are large for the appliance as defined by the fuel load calculator.

3.33. L1 - Start-up – period of the test when the fire is started and the appliance has kindling and startup fuel in the firebox.

3.34. L2 - High-fire Phase – period of the test when the unit has a small coal bed, and the stove air settings are fully open. It is intended to replicate periods when homeowners are trying to quickly heat an area, shortly after starting or restarting the appliance.

3.35. L3 - Maintenance-fire phase – period of the test when a fire is maintained with a medium-sized coal bed, and a smaller batch of wood made up of two large pieces. This is intended to simulate a period when the operator is trying to maintain consistent heat output.

3.36. L4 - Low-burn Rate Phase – period of the test when the stove has a large coal bed, the stove is fully loaded, and the adjustable air settings are set to produce the lowest possible burn rate and have the lowest air settings. It is intended to simulate when the operator is trying to maintain heat over a long time, such as overnight or while away for significant periods of time.

3.37. Low air setting – for purposes of this test method, the lowest air setting on the stove is the setting with the lowest air flow for the appliance. The manufacturer may identify an alternative low setting for the test series. If the test uses an alternative low setting, it must be marked on the stove before testing and must achieve a burn rate of 1.1 dry kg/hr or less during the L4 phase for test runs 2 and 3. This setting must be used whenever the test method calls for a low air setting. No other setting may be used.

3.38. North-south stove – a firebox that has its longest dimension measurement perpendicular to the loading door. In this stove type, logs are loaded so that the ends of the fuel are viewed when loaded.

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

3.40. Primary air supply – air supply that introduces air to the wood heater in the combustion chamber and is adjusted to target a desired burn rate. The wood heater manufacturer or test facility can document this through design drawings.

3.41. Secondary air supply – air supply that introduces air to the wood heater such that the burn rate is not altered by more than 10 percent when the secondary air supply is adjusted during the test run. The wood heater manufacturer or test facility can document this through design drawings that show the secondary air is introduced only into a mixing chamber or secondary chamber outside the firebox.

3.42. Significant figure – is any digit that is necessary to define the specific value or quantity. Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number.

3.43. Small fuel pieces – pieces that are small for the appliance as defined by the fuel load calculator.

3.44. Starter fuel – pieces of cordwood that are smaller than small and large pieces but larger than kindling, as defined by the fuel load calculator.

3.45. 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.

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

3.47. Test facility – the area in which the wood heater is installed, operated, and sampled for emissions during a certification test.

3.48. Test fuel charge – the collection of test fuel pieces used in each of the four fuel loads used in the test run. L2, L3, and L4 require that at least 75% of the individual pieces have at least 80% bark on one side of the fuel piece. Bark must not be removed for certification testing. Modifying fuel to obtain proper fuel weights must minimize bark loss. For example, the portion of the fuel with bark must not be removed to meet the required fuel piece weight. Any fuel charge where it appears that bark was purposely removed or shaped must invalidate the certification test.

3.49. Test fuel load – the group of test fuel pieces that are loaded, as specified by phase, throughout the test run. Test fuel must be provided by the certification lab. The manufacturer cannot supply fuel for certification testing.

3.50. Test fuel loading – the arrangement of the test fuel charge.

3.51. Total run fuel load – the amount of wood burned during the entire test run.

3.52. Test fuel loading density – the calculation that determines the weight of the as-fired test fuel load. The calculation is based on the usable volume of the firebox.

3.53. Test run – an individual emission test that includes the four operational phases required by the fueling protocol.

3.54. Usable firebox volume – the calculated volume of the firebox determined using its height, width, and depth as defined in this section. This calculation represents the area where wood is likely to be loaded. If the manufacturer claims that portions of the firebox may not be used in the calculation, a justification must be submitted with the test report. If the justification is not approved, the test results will be deemed unrepresentative for certification purposes. It is highly recommended that manufacturers obtain regulatory approval to the EPA Administrator if making claims that portions of the firebox are not appropriate for inclusion in the calculation.

3.55. Wood heater – an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation.

4. Interferences

None.

5. Summary of Method

5.1. Particulate matter emissions are measured from a wood heater burning cordwood test fuel in a test facility maintained at a set of prescribed ambient conditions. Procedures for operating the appliance, measuring PM and CO emissions, CO2 concentrations, and methods for reducing data and calculating results are provided.

5.2. *Dilution Tunnel*. A dilution tunnel following the specifications detailed in Method 5G-X must be used for particulate measurements.

5.3. *Particulate Matter.* PM emissions are measured in a dilution tunnel specified in Method 5G-X. The mass flow rate in the dilution tunnel is accurately measured. PM emissions are measured in the dilution tunnel using both the filter method specified in Method 5G-X and with a Thermo model 1405-D TEOM using “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”.

5.3.1. Manual Filter Measurements. Full run PM emissions may be measured with Method 5G-X.

5.3.2. Real-time Measurements. Real-time PM emissions are measured with a Thermo model 1405-D 2-channel TEOM using NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel, with a dilution tunnel as specified in Method 5G-X.

5.4. *Carbon Dioxide*. CO2 measurements take place in the stack using Method 3A modified for use in a stack less than twelve inches in diameter for wood heater testing. These measurements must be used to calculate efficiency metrics.

5.5. *Carbon Monoxide*. CO measurements take place in the stack using EPA Method 10 modified for use with a stack less than twelve inches in diameter for wood heater testing. These measurements must be used to calculate efficiency and CO emissions.

5.6. *Efficiency.* Efficiency uses measurements obtained during testing and calculations contained in the test method to determine appliance efficiency.

5.7. *Operation*. Appliance operation is conducted on a cold-to-hot test cycle, meaning that the appliance starts the first test run at room temperature with a firebox that has been vacuumed and removed all ash and ends with the appliance in a heated state. The second and third test runs may start at a warmer temperature if the appliance retains heat from the first run, and ash must be scooped out before starting a test run but not vacuumed.

Testing operates the appliance with operational elements representing start-up emissions, high heat demand, low heat demand, changing air conditions, and refueling. To complete the certification test, the appliance must complete three valid test runs that are averaged to determine the test results.

5.8. *Repeatability.*

5.8.1. For manual air control stoves, three valid test runs must be conducted for certification or audit purposes.

5.8.2. For appliances with automatic air controls, a series of at least three test runs using automatic controls and a single run completed with the heater and controls disconnected from any external power source must be conducted. If the owner's manual provides instructions for using the appliance without power, this test run must be included in assessing appliance performance for certification and audit purposes.

5.9. *Stack Draft.* Stack draft shall be measured and recorded in 1-minute intervals.

6. Significance and Use

6.1. Measurement of particulate matter emission rates is an important test method widely used in the practice of air pollution control.

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

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

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

7. Safety

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

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

8. ***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 near the test appliance.

8.2. *Appliance Flue.*

8.2.1. Steel flue pipe extending to 8.5 ±0.5 ft. (2.6 ±0.15 m) measured from the base (feet) of the appliance tested, and above this level, insulated solid pack type chimney extending to 15 ±1 ft (4.6 ±0.3 m) above the platform scale, and of the size specified by the appliance manufacturer. This applies to both freestanding and inserts type appliances.

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 chimney for home installation (e.g., zero clearance appliance inserts). Such alternative chimney or flue pipe must remain and be sealed with the appliance following the certification test. This applies only to appliances requiring a specialized chimney.

8.2.3. Solid pack insulated chimneys must 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 Platform Scale and Monitor. For monitoring of fuel load weight change. The scale must be capable of measuring weight to within 0.01 kg (0.02 lb.) and calibrated to NIST traceable standards upon installation and before and after every test run with a NIST traceable calibration weight in the range of approximately 50% of expected fuel load weights. This check must be captured through video documentation.

8.4. Barometer. Aneroid or another barometer capable of measuring atmospheric pressure to within 0.1 in. Hg (2.54 mm Hg) with an uncertainty of +/- 0.05 in. Hg (+/- 1.27 mm Hg). NOTE: The barometric pressure reading may be obtained from a nearby National Weather Service station (within 50 miles of laboratory). In this case, the station value (which is the absolute barometric 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. CO Gas Analyzer. A continuous nondispersive infrared (NDIR) analyzer, or equivalent, that measures the CO concentration in the flue gas stream.

8.6. CO2 Gas Analyzer. A continuous NDIR analyzer, or equivalent, that measures the CO_2 concentration in the flue gas stream.

8.7. Dilution Tunnel must meet the requirements of Method 5G-X.

8.8. Dilution Tunnel temperature. A probe with analog or digital data outputs capable of measuring tunnel temperature to within ±0.5 °C (±0.9 °F).

8.9. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.002 in. H_2O.

8.10. Flue Gas Sample Probe. Stainless steel or glass of sufficient length to measure the sample point in stack. A calibrated three-hole probe, per EPA GD-31, should be utilized to account for any gas stratification.

8.11. 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.

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

8.13. 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.

8.14. Flue Gas Conditioning Equipment. A condenser, dryer or other suitable system which removes moisture, condensable organic material and particulate continuously from the sample flue gas.

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

8.16. Flue Gas Temperature Measurement. A type K thermocouple or equivalent located in the centroid of the stack located 8.0 +/- 0.5 ft (2.44 m +/- 150 mm) above the platform scale, capable of measuring with an accuracy of 4.0˚F (2.2˚C) or 0.75% of reading, whichever is greater.

8.17. Flue Gas Composition Measurement. A sample probe and continuous infrared analyzer or equivalent capable of measuring carbon monoxide (CO) and carbon dioxide (CO_2) in the flue gas produced by the appliance tested.

8.18. Fuel Scale. Balance capable of weighing the test fuel charge to within 0.01 kg (0.02 lb.) at a minimum and checked with a NIST traceable standard before and after each use.

8.19. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity to within +/- 4% from 25 to 95% RH.

8.20. IR Gun. Infrared temperature measurement range: -40 C to 750 C (or broader) (-40F – 1382F) with an accuracy of +/- 1.5 deg. C or 2.7 deg. F (or better). Distance to spot size ratio: 15:1 or better (1 inch spot at 15”).

8.21. Moisture Meter. Electrical resistance meter for measuring test fuel moisture to within 2 percent moisture content.

8.22. Temperature sensors. Capable of measuring temperature to within 1.5 percent of expected absolute temperatures with an accuracy of 4.0 ˚F (2.2 ˚C) or 0.75% of reading, whichever is greater.

8.23. Test Facility Temperature Monitor. A thermistor, RTD, Type T-Special thermocouple, or other equivalent device, located centrally in a vertically oriented 150 mm (6 in.) long, 50 mm (2 in.) diameter pipe shield that is open at both ends, capable of measuring temperature to within 1 ˚F of expected temperatures. The monitor shall be located at least 6 feet away from the test stand.

8.24. TEOM. Thermo Fisher Scientific TEOM model 1405-D (Thermo part # 1405D-ANF, excluding models 1405, 1405-DF, or 1405-F) to measure and report continuous particulate matter (PM) measurements in Method 5GX dilution tunnel, and operated according to the NYSERDA Dichot TEOM Standard Operating Procedures.

8.25. Master Lab Clock. A clock with a digital display and 1-second resolution. All real-time (1-minute) data collection systems (including the TEOM) must be synchronized to the master lab clock to within 5-seconds. Stove ignition and all fuel loading events should be started within 5-seconds of the start of the minute as read from the master lab clock.

9. Calibration and Standardizations

9.1. Anemometer. Calibrate the anemometer as specified before the first certification test and every six months thereafter.

9.2. Appliance Platform Scale. Perform a multipoint calibration (at least five points spanning the operational range) of the platform scale before its initial use. The scale manufacturer's calibration results are sufficient for this purpose. Before each certification test, audit the scale with the wood heater in place by weighing at least one calibration weight (Class F) that corresponds to between 20 percent and 80 percent of the expected test fuel charge weight. If the scale cannot reproduce the value of the calibration weight within 0.009 kg (0.02 lb.) or 1 percent of the expected test fuel charge weight, whichever is greater, recalibrate the scale before use with at least five calibration weights spanning the operational range of the scale.

9.3. Barometer. If measuring barometric pressure in the lab, calibrate using a reference pressure monitor calibrator before the first certification test and semiannually after.

9.4. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration (but must be properly leveled, zeroed, and the system leak checked).

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

9.6. Fuel Scale. Calibrate as described in 9.2.

9.7. Moisture Meter. Check as per the manufacturer's instructions before each day of use. Checks must be conducted with internal or external (calibrated resistance block) calibration checks. The moisture meter and resistance block, if used, must be calibrated annually to NIST traceable standards.

9.8. Method 5G-X. Perform all calibrations as required by Method 5G-X.

9.9. Temperature Sensors. Calibrate using at least five points within operating range within specification and in compliance with NIST Monograph 175. To be calibrated before the first certification test and semiannually thereafter.

10. Sampling, Test Specimens, and Test Appliances

10.1. Dilution tunnel setup and manual particulate matter filter sampling must follow Method 5G-X and must follow the specifications listed here.

10.1.1. Liquid water should not be present anywhere in the sampling system for a valid sample. The lab must document (via photograph) the filter at the end test run, before equilibration. The presence of condensed water anywhere in the sampling system invalidates the test run. All data from all invalid test runs must be included in the report. The reviewing authority must make a final determination on invalidated runs. Data from any invalidated test run must not be used to calculate results.

10.1.2. Dilution tunnel temperature must be measured electronically and logged at one-minute intervals near the pitot tube. The thermocouple should be at least 1” away horizontally, and downstream of the Pitot tip and at least 2 diameters upstream of the sample probe location.

10.1.3. The following section details test conditions that must be maintained for a valid test run. A valid test must have no more than two individual deviations from the conditions below to remain a valid run. A third ten-minute deviation invalidates the test run. An example of an individual deviation is a single, ten-minute rolling average where the dilution tunnel exceeded temperature thresholds. Another ten-minute period exceeding the tunnel temperature requirement must be considered a second deviation.

10.1.3.1. The tunnel flow rate must be sufficient to maintain a 1-minute tunnel temperature no higher than 125 °F and no higher than 113 °F on a 10-minute rolling average, excluding periods when the appliance door is open. Two exceedances are allowed of the 10-minute rolling average points in each test run.

10.1.3.2. A minimum average tunnel flow of 600 wet SCFM is required. Higher tunnel flows may be required to meet the parameters of Section 10.1.3 of this test method.

10.1.3.3. All exceedances of the required temperature range in Section 10.1.3 of this test method must be enumerated and described in the test report.

10.1.3.4. Filter trains 1 and 2 results must meet the dual-train comparison requirements of Method 5G-X.

10.1.3.5. Use rounding requirements specified in Section 13.1 of this test method.

10.1.3.6. Use processes specified in Section 10.2 of this test method.

10.2. Sample Collection. The following are required for sample collection:

10.2.1. Teflon coated glass fiber filters as supplied by the TEOM manufacturer for use with the TEOM model 1405-D. These are Pallflex Emfab (TX40) with an exposed diameter of 13 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

10.2.2. *Test Specimens.* Appliances must be supplied as complete systems, including all controls and accessories necessary for installation at the test facility. A full set of specifications, designs, and assembly drawings must be provided in the test report.

10.2.3. Particulate Matter Sampling uses two Method 5G-X sampling trains and a TEOM to obtain real-time data. TEOM data must be used to report the first-hour emission rate, to provide data for phased emissions, and real-time data reporting requirements. All measurements must run through the entirety of the test to obtain full run data.

10.2.3.1. Train 1 and 2 must provide dual sampling trains that must measure PM emissions from run start to run completion. Trains 1 and 2 results must meet the dual-train comparison requirements of Method 5G-X.

10.2.3.1.1. Proportional rate variation (Sampling Ratio) for manual sampling trains must meet Method 5G-X requirements for the full run.

10.2.3.1.2. Filter conditions (flow, temperature) must be monitored, and filter changes may be required as specified in Method 5G-X.

10.2.3.2. TEOM data must be collected at 1-minute intervals for reporting. TEOM operation must follow the procedures listed on the NYSERDA Standard Operation Procedures for Thermo Scientific 1405-D TEOM for use in a dilution tunnel.

10.3. *Flue Gas Measurement System Setup and Calibration*

10.3.1. Install the multi-point flue gas sample probe 2 in. (50 mm) above the flue gas temperature measurement in the stack.

10.3.2. Set up the Flue Gas Measurement System with an appropriate sample flow rate to reach 90% of the final reading within approximately 90 seconds when beginning at ambient levels and responding to a high-level calibration gas.

10.3.3. The Flue Gas Measurement System must record CO and CO_2 concentrations at one-minute- intervals.

10.4. *Draft Measurements.* Place probe on the wall no more than 1/8" from the stack wall into the stack. Measure chimney static pressure (draft) 1.0 ft above the flue collar.

10.5. *Preparation of Appliance*

10.5.1. Wood Heater Installation for Certification Testing. Assemble the wood heater appliance and parts in conformance with the manufacturer's provided User Guide. These User Guide instructions must match all instructions materials developed by the manufacturer and/or their distributors. Place the wood heater on the platform scale and connect the chimney to the appliance. Clean the flue with an appropriately sized, wire chimney brush before initiating Run 1 of the certification test. The test documentation must include the date and time of flue cleaning.

10.5.2. Wood Heater Temperature Monitors (defined in Section 8.22 of this test method).

10.5.2.1. For catalyst-equipped wood heaters, locate a temperature monitor (optional) about 25 mm (1 in.) upstream of the catalyst at the centroid of the catalyst face area, and locate a temperature monitor (mandatory) that will indicate the catalyst exhaust temperature. This temperature monitor is centrally located within 25 mm (1.0 in.) downstream at the centroid of the catalyst face area. Record these locations.

10.6. Conditioning

10.6.1. Wood Heater Aging Prior to Certification Testing. A wood heater of any type must be aged at least 50 hours at a stack temperature of 250 °F or greater before initiating a certification test. The aging procedure must be conducted by the manufacturer or a manufacturer's agent prior to sending the appliance to the testing laboratory. The certification lab cannot be involved with wood heater aging in any manner.

During aging, the appliance must be operated at a variety of burn rates. Documentation for wood heating aging must be included in the test report to include data on individual hourly burn rates. The testing laboratory must not conduct any firing of the appliance prior to conducting the certification test.

10.6.1.1. The manufacturer must supply wood heater aging information for the final test reports. Aging data that must be reported include fuel species burned, scale data to indicate amount of fuel loaded into the appliance for conditioning, air settings used, 1-minute stack temperature data, and catalyst temperature data, if applicable.

10.6.1.2. If an appliance uses a catalytic combustor, it must be engaged according to the User Guide instructions and operate with the catalyst engaged for at least 50 hours during the break-in period. In addition to the reporting requirements listed on 8.1.1, catalytic appliances must also report hourly catalyst exit temperature data to include the dates and hours of operation.

10.6.1.3. Alternatively, the catalyst can be aged before shipping to the lab for testing, but it must have 50 hours of aging at a stack temperature of greater than 250 °F.

10.6.1.4. If the test lab needs to cure the stove prior to certification testing, labs can use an electric heat source, such as heat lamps or resistance coils for curing purposes. Certification test labs cannot build fires in stoves to cure stoves prior to certification testing.

10.6.1.5. If damage to tubes, refractory, or catalysts occur when transporting a stove for certification testing, labs can cure these items in lieu of aging using approaches listed in 10.5.1.4.

10.6.2. User Guide – The manufacturer must complete the following User Guide Instructions contained in Attachment A and supply it to the certification lab for testing.

11. Procedure

11.1. Testing must take place at an EPA approved test lab. Certification testing cannot take place at manufacturer, research, or consultant facilities.

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

11.2.1. The test facility temperature must be maintained between 55 and 87 °F (13 and 30.6 °C) during each test run.

11.2.2. The flue must be discharged into the same space or into a space freely communicating with the test facility. Any hood or similar device used to vent combustion products must not induce a draft greater than 0.005 in. H_2O (1.25 Pa) on the wood heater measured when the wood heater is not operating.

11.2.3. 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.

11.2.4. Locate the test facility temperature monitor on the horizontal plane that includes the primary air intake opening for the wood heater. Locate the temperature monitor 3 to 6 ft. (0.9 to 1.8 m) from the front of the wood heater in the 90° sector in front of the wood heater.

11.2.5. Use an anemometer, or equivalent device, to measure the air velocity within two feet of the appliance at the air inlet. Measure and record the room air velocity before the ignition period in L1 Startup and once immediately following the test run completion. Air velocities within 0.6 m (2 ft) of the test appliance and exhaust system must be less than 0.25 m/sec (50 ft/min) without fire in the unit.

11.2.6. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run using equipment as specified in Section 8 of this test method.

11.3. Wood Heater Firebox Volume.

11.3.1. Full firebox volume. Determine the firebox volume using the definitions for height, width, and length as defined in the test method in Section 3 of this test method. Measurements must include areas adjacent to and above a baffle.

11.3.2. Usable firebox volume: Volume adjustments must be made due to the presence of permanent fixtures such as firebrick, grates, tubes, and other permanent fixtures. The usable firebox must represent the space where wood can be loaded by the homeowner. All adjustments must be detailed in the test report and must conform to the definition of usable firebox volume contained in this test method. No other volume adjustments are allowed.

11.3.2.1. Use the width or length dimensions inside the firebrick if the firebrick extends more than one-third of the usable firebox height. Width and length dimensions must extend to the metal wall of the wood heater above the firebrick or permanent obstruction if the firebrick or permanent obstruction extends less than one-third of the firebox height.

11.3.2.2. If a log retainer or grate is a permanent structure and prevents any wood or charcoal from occupying a volume and is greater than one-quarter the height above the door, the area where wood or charcoal may not physically reside must be subtracted when determining the usable firebox volume.

11.3.2.3. If the stove is an east west stove, exclude the area above the ash lip if that area is less than 10 percent of the usable firebox volume. Amounts greater than 10 percent of the firebox volume cannot be subtracted. If the stove is a north south stove this area may not be excluded from the usable firebox volume.

11.3.2.4. Exclude areas adjacent to and above a baffle (up to two inches above the fuel loading opening).

11.3.2.5. If a manufacturer deems certain areas of the firebox unusable for fuel load calculations not detailed in this test method, written documentation stating the basis for that claim and supporting photographic image(s) must be provided. Only areas where fuel cannot be loaded can be subtracted from the full firebox volume. Deviations from the allowances described in this method shall render the test series invalid.

11.4. Test Fuel. The test fuel must conform to the following requirements and meet specifications as required by the fuel loading calculator:

11.4.1. Fuel Species. Untreated, <u>air-dried</u>, cordwood fuel.

11.4.1.1. Allowable species: maple with a specific gravity of 0.46 to 0.57 as defined by USDA.[1]

11.4.1.2. Kiln-dried fuel is not permitted. Kiln-dried fuel includes elevating air temperature above ambient.

11.4.1.3. Fuel must be free of decay, fungus, or other contaminants.

11.4.1.4. All fuel used for testing must be supplied by the certification test laboratory. The manufacturer cannot provide fuel for certification testing.

11.4.2. Fuel Moisture.

11.4.2.1. Measurements

[1] Smith, et al., October 2009. Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species in Found in North America. Northern Research Station, NRS-38, USDA. Available at: https://research.fs.usda.gov/treesearch/download/34185.pdf

11.4.2.1.1. Fuel moisture must be measured within 24 hours of using the fuel for the test and must be bagged or stored in a humidity-controlled environment until 2 hours prior to testing. A humidity-controlled environment is one where fuel is not subject to conditions that would remove moisture from the fuel, such as fans or a heating source, and maintain relative humidity levels greater than 75%.

11.4.2.1.2.Determine the test fuel moisture content with a calibrated electrical resistance meter or other equivalent performance meter as defined by this test method. Input fuel moisture data into the IDC Cordwood Fuel Calculator.

11.4.2.1.3. Using a fuel moisture meter as specified in Section 8.21 of this test method, determine the fuel moisture content by obtaining three moisture meter readings from each piece and entering the data into the IDC Ful Calculator for Cordwood Stoves.

11.4.2.1.4. Measurements must be made parallel to the grain of the wood. The moisture content readings must be taken at a depth of ½ to ¾ inch from the bark wood interface.

11.4.2.1.5. For triangular pieces or trapezoidal pieces:

11.4.2.1.5.1. Measurement 1 shall be taken on side 1, 2-3 inches from one end of the fuel.

11.4.2.1.5.2. Measurement 2 shall be taken from side 2, 2-3 inches from one end of the fuel.

11.4.2.1.5.3. Measurement 3 shall be taken from a generally flat side of the fuel piece in the center of the fuel piece, using a different side than measurements 1 and 2.

11.4.2.1.6. Measurements on half-round pieces: The half round side must be considered to be two equal sides and moisture readings taken accordingly.

11.4.2.1.7. Round pieces: The three required readings must be taken as specified location with the fuel piece rotated 120 degrees after each reading.

11.4.2.2. Fuel moisture requirements

11.4.2.2.1. The test fuel load must have an average moisture content from 19% to 25%, dry basis using the equation contained within the IDC Fuel Calculator.

11.4.2.2.2. The average moisture content for each fuel piece must be between 19% to 25%, dry basis.

11.4.2.2.3. The individual fuel piece moisture readings must be between 18 and 26% dry basis (db). The average moisture content of a fuel piece must be the average of all the readings taken for each fuel piece.

11.4.2.3. The addition of moisture to previously dried wood is not allowed.

11.4.2.4. It is recommended that the test fuel be stored in a temperature and humidity-controlled room.

11.4.3. Fuel Temperature. The test fuel must be at the test facility temperature of 55 to 87 °F (13 to 30.6 °C) +/-2 ºF.

11.4.4. Fuel Dimensions. The dimensions of each test fuel piece must conform to definitions specified by the protocols using the fuel load calculator.

11.4.4.1. Fuel length:

11.4.4.1.1. The length of the fuel pieces will be determined by the fuel load calculator.

11.4.4.1.2. Measurements must be taken, and the length of the test fuel will be determined by entering the firebox dimensions.

11.4.5. Fuel Loading Direction

11.4.5.1. Fuel loading direction must be determined by the firebox measurement.

11.4.5.1.1. Stoves with a depth measurement greater than the width measurement must be tested with the fuel in a north-south configuration and may not test with fuel in an east/west or crisscross configuration (Load 1 and Load 2 only).

11.4.5.1.2. Stoves with a width measurement greater than the depth measurement or a width measurement must be tested with the fuel loaded in an east-west configuration and may not test with fuel in a north-south configuration or crisscross configuration (Load 1 and Load 2 only).

11.4.6. Fuel piece weight for each phase of the protocol must be determined by the fuel load calculator.

11.4.6.1. Kindling – must be:

11.4.6.1.1. Pieces of wood less than or equal to 1” in diameter.

11.4.6.1.2. The length of kindling must be 50-100% of the fuel length specified by the fuel load calculator.

11.4.6.1.3. No bark requirements for kindling fuel.

11.4.6.1.4. Fuel species may be any species allowed by Section 11.4.1.1 of this test method.

11.4.6.1.5. Kindling shall be dry with a moisture content <20% moisture content. It is not required to complete or report moisture measurements.

11.4.6.1.6. The length of kindling must be the fuel length specified by the fuel load calculator.

11.4.6.1.7. Kindling fuel must conform to the rule that 5 to 10 pieces of kindling equal 1 pound of kindling (+/- 5%).

11.4.6.2. Starter fuel: pieces of cordwood must be used during the startup phase. Individual piece weight for starter fuel must be determined by the fuel load calculator. Each piece must be triangular, irregular, or circular in a cross-section. Square pieces must not be used (see Figure 1). Pieces that have squared cross sections must be split to represent the typical triangle nature of split wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible and fuel load pieces must be composed of different shapes of wood if using any trapezoidal pieces.

11.4.6.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece must be triangular, irregular, or circular in cross-section. Square pieces must not be used (see figure 1). Pieces that have square cross-sections must be split to represent the typical triangle nature of split wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than two (2) small fuel pieces can be trapezoidal in shape (Figure 2) per fuel load.

11.4.6.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece must be triangular, irregular, or circular in cross-section. Square pieces must not be used (see figure 1). Pieces that have square cross-sections must be split to represent the typical triangle nature of split wood (see Figure 3). Trapezoidal pieces must be minimized to the extent possible. No more than one (1) large fuel piece can be trapezoidal in shape (Figure 2) per fuel load.

Figure 1. Schematic of unacceptable cross-sectional profiles

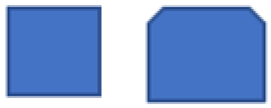
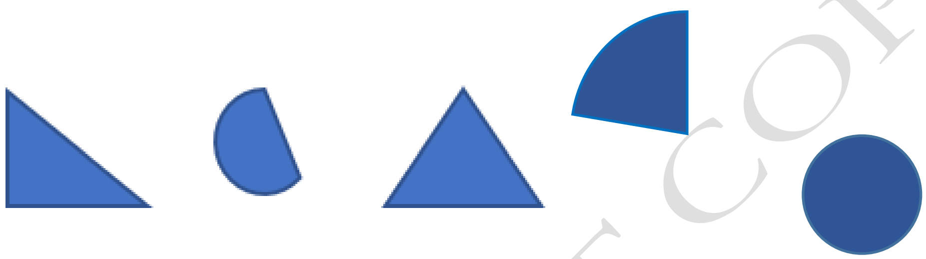


Figure 2. Schematic of undesirable and limited use shapes

Figure 3. Schematics of acceptable cross-sectional profiles



11.5. Sampling Equipment.

11.5.1. Prepare the tunnel PM sampling equipment as defined by the TEOM Protocol.

11.5.2. Prepare all other equipment as defined by method EPA Method 1, 2, 3, 4 and Method 5G-X.

11.6. Manufacturer participation in certification testing.

11.6.1. A representative of the manufacturer may observe testing but may not provide instructions, involve themselves in any part of the certification testing process, or communicate with the certification lab staff, in any form, with regard to testing procedures or equipment once the certification tests begin. The start of the test series begins as soon as the lab places the stove on the test stand and begins fuel preparation for the certification test.

11.6.2. The names of testing witnesses cannot be withheld as confidential business information (CBI). Any deviation from this element invalidates the test series. Manufacturers may file a written post-test protest with the lab (to be included in the test report) if they determine that their appliance was not appropriately operated during the test.

11.7. Test Run Procedure.

11.7.1. All real-time (1-minute) data collection systems (including the TEOM) must be synchronized to the master lab clock. Stove ignition and all fuel loading events should be started within 5-seconds of the start of the minute as read from the master lab clock.

11.7.2. Before each test series, the firebox must be vacuumed. The test series must begin without any ash or other materials in the appliance. Before each test run, ash and remaining wood pieces must be scooped out but not vacuumed. The ash pan must be emptied, if so equipped, at the start of every test run. The stove weight should be zeroed on the appliance scale after cleaning the appliance.

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

11.7.4. Record fuel weight data, temperature measurements, and gas concentrations at 1-minute intervals.

11.7.5. Wood Heater Operation and Adjustments. Record all adjustments made to the air supply controls, adjustments to and additions or subtractions of fuel, and any other changes to wood heater operations that occur during the test period.

11.7.6. Appliance operation during test run

11.7.6.1. Bypass operation for all stoves

11.7.6.1.1. For L1 all bypasses must start in a fully open position. The IDC User Guide must provide specifications for when the bypass must be closed that conforms with requirements in this test method.

11.7.6.1.2. For L2, L3 and L4, all bypasses must be open prior to opening the appliance door and all bypasses must be closed immediately after closing the door.

11.7.6.2. For appliances with blowers or fans, test runs must be conducted as follows:

11.7.6.2.1. Optional fans: appliances that have fans as an optional accessory must complete one test run with the fan running. Two runs must be conducted without the fan running. If the value of that test run during fan confirmation test run is more than 1 g/hr higher, three additional runs must be completed to provide three test runs with the fan and three test runs without a fan.

11.7.6.2.2. Units with a fan permanently installed must complete all runs with the fan operating.

11.7.6.2.3. All test runs should have the fan on the highest setting during the test run except during the following times when the fan should be turned off.

11.7.6.2.3.1. The duration of Phase 1.

11.7.6.2.3.2. When the door is open during Phase 2, 3 and 4.

11.7.6.2.3.3. From the end of Phase 3 until the air is set to the low setting during Phase 4.

11.7.7. The appliance scale should be zeroed at the start of the test after cleaning but before loading any fuel. The weight of fuel burned during the test is the total weight of wood loaded (dry basis) minus the scale reading at the end of the test run.

11.7.8. Run Documentation. The test series must conform to one of the options listed below. Failure to comply with one of the options will result in a failed test series. No video or photos are required for conditioning. Regulatory agencies must have the ability to remotely witness any test.

11.7.8.1. All runs must be video recorded in their entirety. The video must be of sufficient quality (minimum of 480P) to determine fuel characteristics, fuel loading procedures, and firebox conditions during any testing or aging conducted by the test lab.

11.7.8.2. All active periods, as defined by this test method, must be video recorded and inactive periods, if not video recorded in real time, must be video recorded at no more than 1-minute intervals.

11.7.8.3. Failure of the video system does not warrant stopping a test run. The lab should take steps to document any active periods and report all data from test runs, even if documentation requirements are not met.

11.7.9. L1: Start-up Phase.

11.7.9.1. L1 Appliance requirements.

11.7.9.1.1. Stove temperature: internal and external stove temperature shall be measured with an IR gun. Operate the IR gun at the 1” spot distance from the appliance (using this approach readings should be taken 15 inches away, if the ratio is 15:1). For Run 1, the stove temperature must not be different than the ambient laboratory temperature +/- 10 ˚F. For runs 2 and 3, follow requirements in Section 11.9.1. In this case, if Run 1 is invalid or incomplete, the stove must meet Run 1 conditions for at least one valid run. Temperature measurements for the external and internal temperatures must be taken within 15 minutes before starting the test and must be reported in the test report. Temperatures may use an IR gun or temperature sensors.

11.7.9.1.2. Firebox and ash pan must be cleaned and vacuumed before starting Run 1. No ash may be in the stove for the start of run 1. For runs 2 and 3 the firebox should be emptied but not vacuumed, and, if the stove has an ash plan, it should not be emptied.

11.7.9.1.3. Tare the appliance scale after the ash has been removed.

11.7.9.2. L1 Fuel requirements.

11.7.9.2.1. L1 Fuel type – during L1, kindling and starter fuel pieces are used. No other additions are allowed.

11.7.9.2.2. L1 loading density

11.7.9.2.2.1. Kindling loading density

11.7.9.2.2.1.1. For a stove with a usable firebox volume less than one cubic foot, kindling may be up to one pound of kindling and three pounds of starter fuel.

11.7.9.2.2.1.2. A stove with a usable firebox volume between one and four cubic feet must use a loading density of 1 lb. per cubic foot for dry kindling, +/- 5%, and 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that must be used.

11.7.9.2.2.1.3. A stove with a full firebox measurement greater than four cubic feet must use a loading density of 0.5 lb. per cubic foot for dry kindling, +/- 5%, and 3.5 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that must be used.

11.7.9.2.3. L1 fuel loading structure: The fuel loading structure must be a bottom-up configuration with kindling underneath the starter fuel. Fuel can be placed in a crisscross structure.

11.7.9.3. L1 Operational parameters.

11.7.9.3.1. Record the weight of the L1 fuel charge prior to loading. This is the initial L1 scale weight to be used in the fuel calculator.

11.7.9.3.2. All kindling and starter fuel must be in the firebox prior to ignition.

11.7.9.3.3. Settings

11.7.9.3.3.1. Manual appliances: All air settings are fully open.

11.7.9.3.3.2. Automatically controlled appliances: the appliance air settings should be those used to achieve maximum heat output. During this phase all air control must not be modified setting, and the appliance must operate as dictated by automatic controls.

11.7.9.3.3.3. Single burn-rate stoves with no air settings have no air setting requirements.

11.7.9.3.4. Light the fire with a torch for a period of no more than 60 seconds.

11.7.9.3.5. Immediately after lighting the fire and completing the photo requirement, the appliance door must be moved to a cracked open position. Cracked open position is defined as opening no more than one inch. The appliance door must be closed within 5 minutes after the start of the test run.

11.7.9.3.6. L1 Fuel Adjustments:

11.7.9.3.6.1. Up to three fuel adjustments are allowed in the startup phase.

11.7.9.3.6.2. The door may be open for 30 seconds during each fuel adjustment.

11.7.9.3.6.3. All fuel adjustments must be documented in the test report notes and summary.

11.7.9.3.7. L1 End of Phase – the end of the L1 phase is defined by the weight specified by the fuel load calculator. This end weight value represents 17.5% of the L2 fuel load weight (wb) (+/- 2%). The L1 phase must end at the end of the minute when the scale indicates that value and uses the actual value not the 1-minute average value. The scale weight at the end of the phase for use in the fuel calculator is the last 1-minute observed value prior to loading L2.

11.7.9.3.8. L1 Documentation – Video of the appliance during the entire test run or active periods to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coalbed, and when the door is closed. The video should be sufficient to determine fuel positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo-document the fuel charge separately and load photos into the IDC Fuel Calculator prior to loading. Door positioning must be documented by the video. Additionally, calibrations, leak checks, filter changes must also have photo documentation provided in the test report. For run 1, the video or photo shall document that the stove was vacuumed, and no ash was in the stove for run 1.

11.7.10. *L2: High-fire Phase* – the L2 phase commences when the L1 phase ends. The test time recorded for the end of L1 is the same time as the start time of L2.

11.7.10.1. L2 Appliance requirements.

11.7.10.2. The scale weight for the start of L2 for use in the fuel calculator is weight at the end of L1 as defined in 11.7.8.5 plus the weight of the L2 fuel charge prior to loading.

11.7.10.3. L2 Fuel requirements.

11.7.10.3.1. L2 piece size – during the L2 phase, small cordwood pieces by weight, as defined by the fuel load calculator, are used.

11.7.10.3.2. L2 loading density: 7 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.7.10.3.3. L2 loading structure. Fuel must be placed in the loading direction specified by the IDC fuel calculator. Fuel shall be loaded to ensure good airflow, so pieces may be offset by an angle up to 40-60 degrees.

<u>Allowed</u>

<ins>Not allowed</ins>


11.7.10.3.4. L2 Operational parameters.

11.7.10.3.4.1. The lab may chop the coal bed with a fuel piece prior to loading L2 fuel charge for coal bed leveling purposes but may not manipulate the coal bed to specific conditions, such as creating slopes, or valleys. During the L2 phase, the tester cannot stir the coal bed, clear ash grates, or clear air vents.

11.7.10.3.4.2. Open the door upon completion of the L1 phase and load the L2 fuel load within 60 seconds. The appliance door must be closed within 60 seconds of opening the door.

11.7.10.3.4.3. End of Phase – The L2 phase must end at the end of the minute when the scale indicates that 80% of the L2 fuel load weight (+/- 2%) has been consumed. The scale weight at the end of the phase for use in the fuel calculator is the last 1-minute logged observed prior to loading L3.

11.7.10.3.5. Air settings

11.7.10.3.5.1. Manually controlled appliances. During the start of the phase air settings must be fully open to achieve maximum heat output. When 50% of the L2 fuel load mass has been consumed, the air settings must be moved to the lowest settings.

11.7.10.3.5.2. Automatically controlled appliances: At the start of the phase settings must be set to those used to achieve maximum heat output. When 50% of the L2 fuel load mass has been consumed, the control systems must be moved to the control settings to achieve the lowest burn rate. Air control settings must not be modified after moving to lowest heat output setting, and the appliance must operate as dictated by the automatic controls.

11.7.10.3.5.3. Fixed air setting stoves with no user adjustable air controls have no air setting requirements.

11.7.10.3.6. L2 Fuel Adjustments. No fuel adjustments allowed during L2.

11.7.10.4. L2 Documentation – Video of the test during active periods to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coalbed, and when the door is closed. The video must be sufficient to determine fuel positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading. Door positioning must be documented in the video.

11.7.10.5. *L3: Maintenance-fire Phase* – the L3 phase commences at the same test time recorded for end of L2.

11.7.10.6. L3 Appliance Requirements.

11.7.10.6.1. The scale weight for the start of L3 for use in the fuel calculator is the weight at the end of L2 as defined in 11.7.9.2.7 plus the weight of the L3 fuel charge prior to loading.

11.7.10.7. L3 Fuel Requirements.

11.7.10.7.1. Fuel type – during the L3 phase, large cordwood pieces are used. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.7.10.7.2. L3 Fuel loading structure: fuel will be loaded in one direction per the direction specified in IDC fuel calculator.

11.7.10.7.3. L3 loading density: 5 lb. per cubic foot, +/- 5%. The fuel load calculator will define the total load weight and the range of allowable piece sizes by weight.

11.7.10.8. L3 Operational Parameters:

11.7.10.8.1. Open door upon completion of the L2 phase and load the maintenance-fire fuel charge. The lab may chop the coal bed prior to loading L3 fuel charge for coal bed leveling purposes but may not manipulate the coal bed to specific conditions, such as creating slopes, or valleys. The tester cannot stir the coal bed, clear ash grates, or clear air vents.

11.7.10.8.2. Air controls

11.7.10.8.2.1. Manually controlled air settings: must be placed in the fully open position for the first five minutes of the phase and then returned to the low air setting.

11.7.10.8.2.2. Automatically controlled air settings: must be placed in the maximum heat output setting for the first five minutes and then shifted to the lowest heat output setting. Air control settings must not be modified after moving to the lowest heat output setting, and the appliance must operate as dictated by the automatic controls.

11.7.10.8.2.3. Fixed air setting stoves with no user adjustable controls have no air setting requirements.

11.7.10.8.3. L3 Load - L3 fuel must be loaded and the door closed within 30 seconds of the door opening. Close the loading door immediately after loading the L3 fuel charge.

11.7.10.8.4. End of Phase. The L3 phase must end at the end of the minute when the scale indicates that 90% of the L3 fuel load weight (+/- 2%) has been consumed. The scale weight at the end of the phase for use in the fuel calculator is the last 1-minute observed value prior to loading L4.

11.7.10.9. L3 Fuel Adjustments: If there is a ten-minute period without 0.10 lb. weight change at any point during the L3 phase, a fuel adjustment must be made to increase the burn rate. The door may be open for up to 30 seconds for fuel adjustments. Only two fuel adjustments may be made during the L3 phase. If after the second fuel adjustment, another ten-minute period of no weight change (0.10 lb.) occurs, the run ends, and it is a failed test run.

11.7.10.10. L3 Documentation – Video of the test during active periods to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coalbed, and when the door is closed. The video must be sufficient to determine fuel positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading. Door positioning must be documented by the video.

11.7.11. *L4: Low burn rate phase* – L4 phase commences immediately after L3 ends. The test time recorded for end of L3 is the same as the start time of L4.

11.7.11.1. L4 Appliance Requirements.

11.7.11.1.1. The scale weight for the start of L4 for use in the fuel calculator is the weight at the end of L3 as defined in 11.7.10.6 plus the weight of the L4 fuel charge.

11.7.11.2. L4 Fuel Requirements

11.7.11.2.1. L4 fuel type – a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by weight, must be large pieces.

11.7.11.2.2. L4 Loading structure: fuel will be loaded in one direction per the direction specified in IDC fuel calculator.

11.7.11.2.3. L4 loading density: The fuel load calculator specifies a load volume of 12 lb/ft^3 +/-5%. Fuel must be loaded in a manner to maximize the number of pieces that will fit in the stove without using force. All large pieces, as defined by the fuel calculator, must be loaded. If all fuel pieces cannot be loaded, remove smaller pieces from the fuel load.

11.7.11.3. L4 Operational Parameters:

11.7.11.3.1. Start of L4. L4 commences upon completion of the L3 maintenance-fire phase immediately before the door opens to load the L4 fuel load. The test time recorded for the end of L3 is the same time as the start time of L4. No minutes from the L4 loading events can be included in L3.

11.7.11.3.2. Load the L4 fuel charge within two minutes (120 seconds). The lab may chop the coal bed prior to loading the L4 fuel charge for coal bed leveling purposes, using a fuel piece but may not manipulate the coal bed to specific conditions, such as creating slopes, valleys, or clearing air inlets. Stoves with fixed grates can have 30 seconds of coal bed stirring prior to loading the fuel. If there are no fixed grates, the tester cannot stir the coal bed, clear ash grates, or clear air vents.

11.7.11.3.3. The door may be in the 1" cracked position for up to five minutes from the beginning of the L4 phase.

11.7.11.3.4. Air controls must be placed in a fully open position for the first ten minutes of the L4 phase and then returned to the low air setting.

11.7.11.3.5. End of Phase. The L4 phase and the test run must end at the end of the minute when the scale indicates that 80% of the L4 fuel load weight (+/- 2%) has been consumed. The scale weight at the end of the phase for use in the fuel calculator is the last 1-minute observed value prior to ending the test run.

11.7.11.4. L4 Fuel Adjustments.

11.7.11.4.1. Unlimited fuel adjustments are allowed within the first five minutes of the L4 phase. After ten minutes, air control(s) must be moved to their lowest position. A picture of the air setting used must be included in the test report.

11.7.11.4.2. Only two fuel adjustments may be made during the first hour. If after the second fuel adjustment another ten-minute period of no weight change (0.10 lb.) is observed, the run ends, and it is a failed test run.

11.7.11.4.3. No fuel adjustments are allowed after the first hour of the L4 phase.

11.7.11.5. L4 Documentation - Video of the test during active periods to clearly show appliance settings, fuel charge placement while loading, changes in appliance settings, coalbed, and when the door is closed. The video must be sufficient to determine fuel positioning, coal bed conditions, appliance operation, and fuel charge combustion conditions. Photo of the fuel charge prior to loading. Door positioning must be documented by the video.

11.8. Test Run. A complete test run requires the completion of all four burn phases (L1, L2, L3, and L4) and fuel loads. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel must contact the Agency Administrator to obtain written approval for an alternative loading arrangement.

11.9. Test Run Requirements. The following describes the required parameters for each test run. Each emission test run must include all phases of the operational and fueling protocol run in order as described in this test method.

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

11.9.1.1. Run 1 – The appliance must have an internal and external starting temperature within +/- 10 ˚F (5.6 ˚C) of ambient laboratory temperature at the beginning of Run 1.

11.9.1.2. Run 2 – The second test run may commence 20 hours after the start of Run 1 or when external top and side stove temperatures are less than 200 ˚F. Stove coals and ash may remain in the stove until 1 hour before conducting Run 2. All coals and ash must be removed, but not vacuumed, within 60 minutes of commencing Run 2.

11.9.1.3. Run 3 – The third test run may commence 20 hours after the start of Run 2. Stove coals and ash may remain in the stove until 1 hour before conducting Run 3. All coals and ash must be removed, but not vacuumed, within 60 minutes of commencing Run 3.

11.9.2. If a wood heater fails to complete all four phases of the test run, the run must be considered an incomplete test run. The lab must complete all emission measurement practices, including weighing filters and reporting filter data for any incomplete test run and convey this information in the test report.

11.9.2.1. If there is no weight change, defined as 0.10 lb., for a consecutive period of 40 minutes at any point during the test, the unit has stopped combustion, and the test run must be deemed incomplete.

11.9.3. If a test run violates any test method parameters in this or a referenced test method, the test must be deemed invalid. The lab must complete all emission measurement practices, including weighing filters and reporting filter data for any incomplete test run. Data for the invalidated test run must be included in the test report, but the data must not be used in the calculation of average emission values.

11.9.4. In the event of a force majeure, the manufacturer must petition the Administrator for an extension of the deadline(s) by which they are required to conduct an initial or subsequent performance test required by applicable regulations, and the run must be considered an aborted run, if the EPA Administrator determines that the event was force majeure. If during certification testing a critical component of the stove is damaged or breaks, the certification test will be stopped and considered an aborted test run.

11.9.5. If damage is noted during a test, repairs must be made by the manufacturer (or by laboratory personnel with written directions from the manufacturer). If the repair involves components that need aging, the appliance must then undergo another round of wood heater aging as specified in section 10.6 of this test method. These components may include but are not limited to catalyst elements, gaskets, and refractory components. The aging process is intended not only to 'cure' the stove 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 of the failed component.

11.10. Test Series Completion. Once three valid runs have been completed, the testing series has been completed. No additional runs may be completed except for the no power mode test for automated appliances, if required.

11.10.1. Once three valid test runs have been completed, the lab may not conduct additional test runs, except for automatically controlled appliances that must conduct a fourth "no-power" test run.

11.10.2. The measurement data and results of all runs, including invalid and incomplete test runs, must be reported regardless of which values are used in calculating the test results.

11.10.3. No test run data can be eliminated from the reporting requirements of this method.

11.10.4. After six test runs (not including the power out run for automatic appliances), including invalid or incomplete test runs, the test series shall be concluded and a test report generated.

11.11. Continuous PM Data Recording.

11.11.1. All TEOM data must be collected and recorded at intervals of 1 minute. TEOM operation must follow the procedures listed in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

11.11.2. Data must be reported in an Excel or compatible spreadsheet following the minimum data reporting requirements. All electronic files, including raw instrument data, must be submitted as part of the test report. Electronic spreadsheet files must be supplied as part of the publicly available test report and may not be held as confidential business information.

11.11.3. This method does not use any measurement of ambient background PM levels. Lab ambient PM levels may not be subtracted from the filter measurements.

12. Quality Control Measures

12.1. Conduct sampling equipment leak checks and flow checks pre- and post-test.

12.2. Conduct all checks required by Method 5G-X, EPA Method 3A modified for RWH testing, and EPA Method 10 modified for RWH testing.

12.3. 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. Additional quality control measures are included in the TEOM Operating Procedure.

13. 0Data Analysis and Calculations.

13.1. Data analysis and calculations. All calculations shall conform to the most recent version of the document titled, " Formulas and Calculations - Integrated Duty Cycle Test Method for Cordwood Stoves." The most recent version has been included as Attachment B.

13.2.Rounding

13.2.1. All calculations must be conducted using all decimal values provided by the instrumentation or recorded by the operator.

13.2.2. No truncation of data is acceptable until the final result has been calculated.

13.2.3. Only the final calculation of the PM emissions rate must be rounded to three significant figures.

13.2.4. When rounding off a figure, the following procedure should be used. If the first digit to be discarded is less than five, the last digit retained should not be changed. When the first digit discarded is greater than five, or if it is a five followed by at least one digit other than zero, the last figure retained should be increased by one unit. When the first digit discarded is exactly five, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number.

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

14.1. General requirements

14.1.1. All required data 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. Formula used for all calculations must be accessible for review.

14.1.2. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

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

14.2. Introduction

14.2.1. Purpose of test: certification, audit, research.

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

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

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

14.2.5. A list of people who conducted testing on the appliance, participated in test preparation, or witnessed the certification testing. This list must clearly specify their roles in the testing program for the appliance. The list must include the participant's name, title, company, contact information and the purpose of their participation.

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

14.3. Summary and Discussion of Results

14.3.1. Test Facility Information. Report:

14.3.1.1. Test facility temperature before and after test.

14.3.1.2. Air velocity before and after test runs.

14.3.1.3. Humidity before and after test runs.

14.3.1.4. Barometric pressure before and after test runs.

14.3.2. Emissions data

14.3.2.1. Summary table containing testing results. Table must include test run number, average burn rate for entire run and each phase, particulate emission rate for full run, particulate emission rate for each load phase (L1, L2, L3, L4), efficiency for the full run and L2, L3, L4, burn time for total run and each phase. The table must also include an average of all three runs for each parameter.

14.3.2.2. For each test run:

14.3.2.2.1. Real-time data for all emission measurements

14.3.2.2.2. Phase efficiency data for L2, L3, and L4

14.3.2.2.3. Full run efficiency

14.3.2.2.4. Full run PM data reported for TEOM and manual filter pulls in grams, pounds per million Btu output, grams per kilogram of dry fuel, and grams per hour. Each test run shall also report how many filters were used during the test run.

14.3.2.3. PM emissions by phase using TEOM data in grams, pounds per million Btu output, grams per kilogram of dry fuel, and grams per hour.

14.3.2.4. PM Plots. A plot of PM emission rate in grams/hour vs. time at 1-minute intervals, for the entire test period, for each run. The report must include reporting the maximum 60-minute grams per hour on a rolling basis for the test run.

14.3.2.5. For each test run: report TEOM flow and temperature and verification of all TEOM data validation parameters as required in NYSERDA Standard Operation Procedures for Thermo 1405-D TEOM for use in a dilution tunnel.

14.3.3. Summary of other data

14.3.3.1. test facility conditions

14.3.3.2. catalyst temperature averages

14.3.3.3. test fuel charge weights – total and by phase.

14.4. Discussion.

14.4.1. A narrative discussion, if needed, detailing any issues or anomalies that arose during each test run and how those were handled, including comments about the fuel, and loading of the appliance. Comments on fuel, loading, analysis, and anything that may impact the reported result(s).

14.4.2. Details of deviations from, additions to or exclusions from the test method, and their data quality implications on the test results (if any), as well as information on specific test conditions, such as environmental conditions. An explanation of the deviations, additions, or exclusions must be provided along with an analysis as to why these elements had no impact.

14.5. Testing Process description:

14.5.1. A description of the test procedures used for the test series

14.5.2. Firebox calculations

14.5.2.1. Data, drawings, and calculations used to determine firebox volume to include volume, height, width, lengths, weight, and volume adjustments that informed the calculation of the full and usable firebox size.

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

14.5.3. Appliance operation during the test

14.5.3.1. Summary of air controls and bypasses on the appliance.

14.5.3.2. Details and documentation of air supply settings used during testing.

14.5.3.3. Details on any air control adjustments made during a test run.

14.5.4. Test fuel properties – the report must include data from the IDC Cordwood Stove Fuel Calculator.

14.5.5. Sampling information

14.5.5.1. A schematic with measurements for the dilution tunnel used during testing.

14.5.5.2. A schematic or other drawing showing the location of all required test equipment.

14.5.5.3.A photo of the appliance on the stand during testing to show the appliance and dilution tunnel.

14.5.5.4.Description of the sampling location relative to the wood heater, including drawing or photographs.

14.5.5.5. Data on manual filter sampling blanks per Method 5G-X.

14.5.6.Equipment. A list of equipment used for testing.

14.6. Quality Control and Assurance Procedures

14.6.1. Results of calibration procedures detailed in test methods used to include this test protocol, Method 5G-X, NYSERDA TEOM protocol, OTM for EPA Method 3A, and OTM for EPA Method 10.

14.6.2. Test method quality control procedures to include TEOM leak and flow checks, stratification (velocity) checks, tunnel flow range results, filter temperature range verification and dilution tunnel RH verification.

14.7. Appendices

14.7.1. Raw data.

14.7.1.1. Real-time data.

14.7.1.2. Copies of all files or sheets for sampling measurement, temperature records, and other materials used by lab related to testing.

14.7.1.3. Copies of all lab notes or checklists used during testing.

14.7.2. Calibration Results.

14.7.2.1.Summary of all calibrations, check, and audits pertinent to the certification.

14.7.2.2. Test Equipment Calibration and Audit Information. Report calibration and audit results for the platform scale, test fuel balance, test fuel moisture meter, and sampling equipment including volume metering systems and gaseous analyzers.

14.7.3. Photographs/videos of fuel loading and air flow settings.

14.7.4. Correspondence. Any correspondence to include written, electronic or verbal communications regarding appliance testing. Items must include:

14.7.4.1. Request to conduct testing.

14.7.4.2.Notice to EPA to conduct test, and any modifications to that request.

Appendix A. Testing Instructions

The following sheet must be used for testing.

Manufacturer			
Model			
Serial #			
Using an alternative low setting		id alt low setting	
air control (select one from list)	manual air controls		
L1			
door cracked after lighting			
door closing time			
bypass operation			
L2			
bypass operation			
L3			
bypass operation			
L4			
door cracked after lighting			
door closing time			
bypass operation			
for IA Project			
Full Firebox Calcuation			
	Side 1	Center	Side 2
Width			
Depth			
Height			
Full firebox volume			
Usable Firebox Cacluation			
Item	used	Area subtracted	Final Usable Firebox Volume
log retainer grate			
ash lip (east west stoves only), cannot exceed 10% of firebox volume			
baffle			
Other, as approved by PM			
Firebox Calculations			
Full Firebox Volume			
Area Subtracted			
Usable Firebox Volume			

Appendix B. Calculations document

This section provides information for calculations used in IDC testing. This data includes calculating results from the IDC protocol, TEOM SOP, and emission measurements.

B-1.Nomenclature

$\Delta\bar{C}^{TEOM}_{PM,unadj.}$: relative difference of run-average unadjusted PM concentrations measured by TEOM. This variable denoted by $\%D$ in NYSERDA TEOM SOP.	Section 6.2.2
ΔER^{5GX}_{PM} (%): Dual Train Comparison of the PM emission rates measured by Method 5G-X. This variable denoted by $\%D$ in Method 5G-X.	Section 6.1.3
ΔH_{vap} ($\frac{\text{kJ}}{\text{kg}}$): enthalpy of water vaporization at 20 (°C), equal to 2442 ($\frac{\text{kJ}}{\text{kg}}$).	Section 4.1
ΔP_t (in. Hg): velocity head of diluted stack gas in the tunnel, averaged over one minute. In the EPA Method 2 document, this variable is denoted by Δp.	Section 5.1
Δt_L (h): time duration of the phase L (L1, L2, L3, L4, or run).	Section 2.3.7
Δt^{TEOM}_L(m): number of minutes of TEOM valid data in burn phase L or the entire IDC run.	Section 6.2.2
η_{TCC} (%): stove thermal efficiency based on the simplified Total Combustible Carbon method.	Section 4
θ^{TEOM}_L (%): TEOM data capture (percentage of valid TEOM data) in burn phase L or the entire IDC run.	Section 6.2.2
ω_a ($\frac{\text{kg}}{\text{kg}}$): ambient (lab) water-air mixing ratio (mass of water vapor per unit mass of ambient dry air).	Section 4.3
A_t (ft^2): cross -sectional area of stack.	Section 5.2
AFR ($\frac{\text{kg}}{\text{kg}}$): dry air-to-fuel ratio.	Section 4.3
C_{CO} (%vd): corrected CO concentration measured on 1-min intervals.	Section 3.1
$C_{CO,obs}$ (%vd): observed CO concentration measured on 1-min intervals (gas analyzer output).	Section 3.1
$C_{CO,0}$ (%vd): CO concentration, the average of pre- and post-test zero responses.	Section 3.1

$C_{CO,MA}$(%vd): CO concentration, the true concentration of the calibration gas.	Section 3.1
$C_{CO,M}$(%vd): CO concentration, the average of pre- and post-test calibration responses.	Section 3.1
C_{CO_2} (%vd): corrected CO_2 concentration measured on 1-min intervals.	Section 3.1
$C_{CO_2,obs}$ (%vd): observed CO_2 concentration measured on 1-min intervals (gas analyzer output).	Section 3.1
$C_{CO_2,0}$ (%vd): CO_2 concentration, the average of pre- and post-test zero responses.	Section 3.1
$C_{CO_2,MA}$(%vd): CO_2 concentration, the true concentration of the calibration gas.	Section 3.1
$C_{CO_2,M}$(%vd): CO_2 concentration, the average of pre- and post-test calibration responses.	Section 3.1
$C_{CO_2,si}$ (%vd): theoretical concentration of carbon dioxide in the simplified TCC method.	Section 4.2
C_{N_2}(%vd): concentration of nitrogen in air, equal to 78.084%.	Section 4.3
$C_{O_2,si}$(%vd): concentration of oxygen in the stack gas in the simplified TCC method.	Section 4.3
$C_{p,ds}(\frac{\mathrm{kJ}}{\mathrm{kg.K}})$: average constant-pressure specific heat of the dry stack gas.	Section 4.3
C_{p,H_2O} $(\frac{\mathrm{kJ}}{\mathrm{kg\ K}})$: specific heat of the water vapor, equal to 1.9 $(\frac{\mathrm{kJ}}{\mathrm{kg\ K}})$	Section 4.3
C_{pitot}: pitot tube dimensionless baseline coefficient, equal to 0.99±0.01 for a standard pitot tube. This variable is denoted by C_P in EPA Method 2.	Section 5.1
$C_{PM}^{5GX(a)}$ $(\frac{\mathrm{g}}{\mathrm{m}^3})$: PM concentration measured by filter a in Method 5G-X method. This variable is denoted by C_s in EPA Method 5G.	Section 6.1.2
$C_{PM}^{5GX(b)}$ $(\frac{\mathrm{g}}{\mathrm{m}^3})$: PM concentration measured by filter b in Method 5G-X method. This variable is denoted by C_s in EPA Method 5G.	Section 6.1.2
C_{PM}^{TEOM} $(\frac{\mathrm{\mu g}}{\mathrm{m}^3})$: Average adjusted PM concentration measured by TEOM.	Section 6.2.3

$C_{PM,unadj.}^{TEOM}$ ($\frac{\mu g}{m^3}$): Average unadjusted PM emission concentration measured by TEOM.	Section 6.2.1
$C_{PM}^{TEOM(a)}$ ($\frac{\mu g}{m^3}$): adjusted PM concentration from channel a of the Dichot TEOM (left channel, "PM-2.5 raw MC")	Section 6.2.3
$C_{PM}^{TEOM(a),raw}$ ($\frac{\mu g}{m^3}$): raw PM concentration measured by channel a of the Dichot TEOM (left channel, "PM-2.5 raw MC")	Section 6.2.1
$C_{PM,unadj.}^{TEOM(a)}$ ($\frac{\mu g}{m^3}$): unadjusted PM concentration from channel a of the Dichot TEOM (left channel, "PM-2.5 raw MC")	Section 6.2.1
$\bar{C}_{PM,unadj.}^{TEOM(a)}$ ($\frac{\mu g}{m^3}$): run-average of unadjusted PM concentration from channel a of the Dichot TEOM (left channel, "PM-2.5 raw MC")	Section 6.2.2
$C_{PM}^{TEOM(b)}$ ($\frac{\mu g}{m^3}$): adjusted PM concentration from channel b of the Dichot TEOM (right channel, "PM-Coarse raw MC")	Section 6.2.3
$C_{PM}^{TEOM(b),raw}$ ($\frac{\mu g}{m^3}$): raw PM concentration measured by channel b of the Dichot TEOM (right channel, "PM-Coarse raw MC")	Section 6.2.1
$C_{PM,unadj.}^{TEOM(b)}$ ($\frac{\mu g}{m^3}$): unadjusted PM concentration from channel b of the Dichot TEOM (right channel, "PM-Coarse raw MC")	Section 6.2.1
$\bar{C}_{PM,unadj.}^{TEOM(a)}$ ($\frac{\mu g}{m^3}$): run-average of unadjusted PM concentration from channel a of the Dichot TEOM (left channel, "PM-2.5 raw MC")	Section 6.2.2
C_{TCC} (%vd): estimated concentration of total combustible carbon.	Section 4.2
CA (%): the carbon content of the dry fuel.	Section 3.2
CF_{TCC}: Carbon Factor used in the simplified TCC method.	Section 4.2
CO: carbon monoxide	Section 3
CO_2: carbon dioxide	Section 3
d_{fb} (in): firebox depth.	Section 2.2.1
$D_{small\ log}^{lower}$ (in): target diameter lower limit of the small fuel pieces.	Section 2.2.3
$D_{small\ log}^{upper}$ (in) : target diameter upper limit of the small fuel pieces.	Section 2.2.3

$D_{large\ log}^{lower}$ (in): target diameter lower limit of the large fuel pieces.	Section 2.2.3
$D_{large\ log}^{upper}$ (in): target diameter upper limit of the large fuel pieces.	Section 2.2.3
DBR_L ($\frac{\text{kg}}{\text{h}}$): dry burn rate of the phase L (L1, L2, L3, L4, or run)	Section 2.3.7
e_c ($\frac{\text{kJ}}{\text{kg}}$): chemical energy loss through the stack gas per kilogram of the burned dry fuel.	Section 4.2
e_l ($\frac{\text{kJ}}{\text{kg}}$): latent heat loss through the stack gas per kilogram of the burned dry fuel.	Section 4.1
e_{in} ($\frac{\text{kJ}}{\text{kg}}$): input energy per kilogram of the burned dry fuel.	Section 4.1
e_{out} ($\frac{\text{kj}}{\text{kg}}$ or $\frac{\text{Btu}}{\text{lb}}$): stove thermal output energy per unit mass of the burned dry fuel.	Section 4.4
e_s ($\frac{\text{kJ}}{\text{kg}}$): sensible energy loss through the stack gas per kilogram of the burned dry fuel.	Section 4.3
E_{out} (MJ orMMBtu): total stove thermal output energy	Section 4.4
EF_{CO} ($\frac{\text{g}}{\text{kg}}$): mass-basis carbon monoxide emission factor as grams per kilogram of the burned dry fuel.	Section 3.2
EF_{CO} ($\frac{\text{g}}{\text{MJ}}$ or $\frac{\text{lb}}{\text{MMBtu}}$): energy-basis carbon monoxide emission factor as grams (or pounds) per mega Joule (or million BTUs) of stove thermal energy output.	Section 3.2
EF_{CO_2} ($\frac{\text{g}}{\text{kg}}$): mass-basis carbon dioxide emission factor as grams per kilogram of the burned dry fuel.	Section 3.2
m_{CO_2} (g): energy-basis carbon dioxide emission factor as grams (or pounds) per mega Joule (or million BTUs) of stove thermal energy output.	Section 3.2
EF_{PM}^{5GX} ($\frac{\text{g}}{\text{kg}}$): mass-based PM emission factor measured by Method 5G-X as grams of PM per kilogram of burned dry fuel.	Section 6.1.5
EF_{PM}^{5GX} ($\frac{\text{g}}{\text{MJ}}$ or $\frac{\text{lb}}{\text{MMBtu}}$): energy-based PM emission factor measured by Method 5G-X as grams (or pounds) of PM per mega Joule (or million BTUs) of stove thermal energy output.	Section 6.1.5

$EF_{PM,L}^{TEOM}$ $(\frac{\mathrm{g}}{\mathrm{kg}})$: mass-based PM emission factor measured by TEOM over burn phase L or the entire IDC run as grams of PM per kilogram of burned dry fuel.	Section 6.2.6
$EF_{PM,L}^{TEOM}$ $(\frac{\mathrm{g}}{\mathrm{MJ}}$ or $\frac{\mathrm{lb}}{\mathrm{MMBtu}})$: energy-based PM emission factor measured by TEOM over burn phase L or the entire IDC run as grams (or pounds) of PM per mega Joule (or million BTUs) of stove thermal energy output.	Section 6.2.6
ER_{CO} $(\frac{\mathrm{g}}{\mathrm{h}})$: average CO emission rate in a phase or entire run.	Section 3.4
ER_{CO_2} $(\frac{\mathrm{g}}{\mathrm{h}})$: average CO_2 emission rate in a phase or entire run.	Section 3.4
$ER_{PM}^{5GX(a)}$ $(\frac{\mathrm{g}}{\mathrm{h}})$: PM Emission rate measured by filter train a for the entire IDC test run.	Section 6.1.3
$ER_{PM}^{5GX(b)}$ $(\frac{\mathrm{g}}{\mathrm{h}})$: PM Emission rate measured by filter train b for the entire IDC test run.	Section 6.1.3
ER_{PM}^{5GX} $(\frac{\mathrm{g}}{\mathrm{h}})$: average PM Emission rate measured by Method 5G-X for the entire IDC test run.	Section 6.1.3
$ER_{PM,i}^{TEOM}$ $(\frac{\mathrm{g}}{\mathrm{h}})$: 1-minute adjusted PM emission rate measured by TEOM.	Section 6.2.4
$ER_{PM,L}^{TEOM}$ $(\frac{\mathrm{g}}{\mathrm{h}})$: average adjusted PM emission rate measured by TEOM over burn phase L or the entire IDC run.	Section 6.2.4
F_P: dimensionless factor to correct the stack velocity due to the difference in the traverse value and center point velocity value.	Section 5.1
h_{fb} (in): firebox height.	Section 2.2.1
m_{CO_2} (g): dry-basis higher heating value of the wood fuel.	Section 4.1
HY (%): the hydrogen content of the dry fuel.	Section 4.1
IDC: Integrated Duty cycle	-
$K_P(\frac{ft}{s}\left[\frac{(lb/lb-mole)(in.Hg)}{(°R)(in\ H_2O)}\right]^{\frac{1}{2}})$: stack gas velocity equation constant, equal to 85.49	Section 5.1
L_{target} (in): target length of the fuel pieces.	Section 2.2.1

$m_{CO_2}\ (g)$: average lower heating value of the unburned carbon products per mole of the dry stack gas, equal to $m_{CO_2}\ (g)$.	Section 4.2
m_{CO} (g): total mass of CO emission in a phase or entire run.	Section 3.3
$m_{CO_2}\ (g)$: total mass of $m_{CO_2}\ (g)$ emission in a phase or entire run.	Section 3.3
$m_{ds}\ (\frac{\text{kg}}{\text{kg}})$: mass of dry stack gas per unit mass of dry burned fuel.	Section 4.3
$m_{CO_2}\ (g)$: moisture content of the combustion air unit mass of the burned dry fuel.	Section 4.3
$m_{CO_2}\ (g)$: total mass of water in the stack gas per unit mass of the burned dry fuel.	Section 4.3
$m_{H_2O,v}\ (\frac{\text{kg}}{\text{kg}})$: mass of the evaporated water in stack gas per unit mass of the burned dry fuel.	Section 4.1
m_L^{target} (lb): wet-basis target load mass in load L where it stands for kindling, starter, L1, L2, L3, L4.	Section 2.2.4
$m_L^{target\ range}$(lb): wet-basis target load mass range in load L (kindling, starter, L1, L2, L3, L4).	Section 2.2.5
$m_{L,burned}^{db}$ (lb or kg): dry-basis mass of the burned fuel in phase L (L1, L2, L3, L4, or run).	Section 2.3.6
$m_{L,burned}^{wb}$ (lb or kg): wet-basis mass of the burned fuel in phase L (L1, L2, L3, L4, or run).	Section 2.3.6
$m_{CO_2}\ (g)$: minimum allowable wet-basis mass of fuel pieces in load $m_{CO_2}\ (g)$ where (kindling, starter, L1, L2, L3, L4 small, or L4 large).	Section 2.2.6
$m_{L,piece}$ (lb): actual wet-basis mass of the individual fuel pieces in load L (starter, L1, L2, L3, L4 small, or L4 large).	Section 2.3.1
$m_{L,piece}$ (lb): actual wet-basis total mass of fuel load in load L (kindling, starter, L1, L2, L3, L4, L4 small, or L4 large).	Section 2.3.1
$m_n^{5GX(a)}$ (mg): total collected PM mass on filter a in Method 5G-X measurement. This variable is denoted by m_n in EPA Method 5G and NYSERDA Method 5G-X.	Section 6.1.2

$m_n^{5GX(b)}$ (mg): total collected PM mass on filter b in Method 5G-X measurement. This variable is denoted by m_n in EPA Method 5G and NYSERDA Method 5G-X.	Section 6.1.26.1.2
m_{PM}^{5GX} (g): mass of the PM emissions over the entire IDC test run measured by Method 5G-X.	Section 6.1.4
$m_{PM,L}^{TEOM}$ (g or lb): mass of the adjusted PM emission measured by TEOM over burn phase L or the entire IDC run.	Section 6.2.5
$MC_{pin\ X}$ (%): dry-basis moisture content of the fuel wood measured by one of the three pins.	Section 2.3.2
MC_{piece} (%): dry-basis average moisture content of a fuel piece.	Section 2.3.2
MC_{Lx}(%): dry-basis average moisture content of the load.	Section 2.3.3
MC_{run} (%): dry-basis average moisture content of all fuel loads in an IDC test run.	Section 2.3.4
$MW_{ds,TCC}$ $(\frac{\text{g}}{\text{mol}})$: species-averaged molecular weight of the dry stack gas in the simplified TCC method.	Section 4.3
$MW_{TS(wet)}$ $\left(\frac{\text{lb}}{\text{lbmol}}\right)$: molecular weight of the diluted wet stack gas in the tunnel. In the EPA Method 2 document, this variable is denoted by M_s.	Section 5.1
n_L^{target}: target number of pieces of fuel wood for load L (kindling, starter, L1, L2, L3, L4 small, or L4 large).	Section 2.2.7
$P_a(mbar)$: ambient (lab) average air pressure. This variable is denoted as P_{bar} in EPA Method 2.	Section 4.3
P_t $(in.Hg)$: static pressure of diluted stack gas in the tunnel. In the EPA Method 2 document, this variable is denoted by P_g.	Section 5.1
$P_{t(abs)}$ (in. Hg): absolute pressure of diluted stack gas in the tunnel. In the EPA Method 2 document, this variable is denoted by P_s.	Section 5.1
$Q_{0,f(wet)}$ (SCFM): initial volumetric filter (sample) flow rate.	Section 5.3
$Q_{0,s(wet),}$ (SCFM): initial volumetric flow rate of diluted stack gas in the tunnel.	Section 5.3
$Q_{i,f(wet)}$ (SCFM): initial volumetric filter (sample) flow rate at i^{th} minute.	Section 5.3

m_{CO_2} (g): volumetric flow rate of diluted stack gas in the tunnel at i^{th} minute.	Section 5.3
$Q_{t(wet)}$ (SCFM): volumetric flow rate of diluted stack gas (wet) in the tunnel.	Section 5.2
$Q_{t(wet)}^{10-min}$ (SCFM): 10-minute rolling average of volumetric flow rate of diluted stack gas (wet) in the tunnel.	Section 5.2
$Q_{TEOM(a)}$ $(\frac{l}{m})$: flow rate of the TEOM coarse channel (channel).	Section 6.2.1
$Q_{TEOM(b)}$ $(\frac{l}{m})$: flow rate of the TEOM coarse channel (channel).	Section 6.2.1
m_{CO_2} (g) : firebox radius.	Section 2.1.2
RH_a (%): ambient (lab) relative humidity.	Section 4.3
SLM: stack loss method	Section 4
SR_0: dimensionless Initial Sampling Ratio. This variable is denoted by ISR in NYSERDA Method 5G-X.	Section 5.3
SR_i: dimensionless Sampling Ratio for the i^{th} minute. This variable is denoted by SR in NYSERDA Method 5G-X.	Section 5.3
T_a(°C or K): ambient (lab) average air temperature.	Section 4.3
T_s(°C or K): stack gas average temperature.	Section 4.3
$T_{t(abs)}$ (°F or °R): absolute temperature of diluted stack gas in the tunnel. In the EPA Method 2 document, this variable is denoted by $T_{s(abavg)}$.	Section 5.1
TCC: Total Combustible Carbon method.	Section 4
$V_{adj.}$ (ft^3): the adjusted volume.	Section 2.2.1
$V_{f(std)}^{5GX(a)}$ (m^3): total volume of wet gas measured by the mass flow meter in Method 5G-X over the sampling period from filter train a, corrected for the standard condition of 20 (°C) and 1 (atm).	Section 6.1.2
$V_{f(std)}^{5GX(a)}$ (m^3): total volume of wet gas measured by the mass flow meter in Method 5G-X over the sampling period from filter train b, corrected for the standard condition of 20 (°C) and 1 (atm).	Section 6.1.2
V_{fb} (ft^3): firebox net volume.	Section 2.2.1

V_t ($\frac{ft}{s}$): average velocity of diluted stack gas in the tunnel over one minute measurement. In the EPA Method 2 document, this variable is denoted by V_s.	Section 5.1
w_{fb} (in): firebox width.	Section 2.2.1
$W_{L,scale}^{lower}$ (lb): lower limit of the scale target at the end of the load L (starter, L1, L2A, L2, L3, or L4).	Section 2.3.5
$W_{L,scale}^{upper}$ (lb): upper limit of the scale target at the end of the load L (starter, L1, L2A, L2, L3, or L4)	Section 2.3.5
W_0^{scale} (lb): initial reading of the scale before loading the stove.	Section 2.3.5
W_L^{scale} (lb): reading of the scale at the end of the load L (L1, L2A, L2, L3, or L4).	Section 2.3.5
WBR_L ($\frac{\text{kg}}{\text{h}}$): wet burn rate of the phase L (L1, L2, L3, L4, or run)	Section 2.3.7

B-2. Operation and Fueling

Operation and fueling requirements are governed by the September 2025 version of the IDC Cordwood Stove Protocol. This protocol is supported by a companion spreadsheet tool, the IDC Stove Fuel Calculator, which ensures that fuel loading practices remain consistent with the method. The Fuel Calculator defines specifications for fuel piece dimensions and moisture content and provides operational guidance throughout the test run.

The IDC Stove Calculator contains embedded formulas that direct the amount and timing of fuel loading. During testing, laboratory staff must manually enter the event loading times based on readings from the master laboratory clock. All fuel loading events must begin as close as possible to the start of a new minute, as prescribed in the protocol (e.g., 09:00:00 for a 9:00 a.m. start).

The following section outlines the calculations embedded in the Woodstove IDC Fuel Calculator and their locations in the spreadsheet tool.

B2.1 Firebox

Cubic Firebox Net Volume

$$V_{fb} = \frac{1}{12^3}\left(h_{fb} \times d_{fb} \times w_{fb}\right) - V_{adj.} \quad \text{(Eq. 2-1)}$$

where

V_{fb} is firebox net volume (ft^3),

h_{fb} is firebox height (in),

d_{fb} is firebox depth (in),

w_{fb} is firebox width (in),

and $V_{adj.}$ is the adjustment volume (ft^3).

Limits and ranges: Firebox height, depth, and width should be between 1 and 40 (in), and $V_{adj.}$ should be a number between -1 and +1 (ft^3). Note that $V_{adj.}$ will be subtracted from the calculated gross volume. Using a negative $V_{adj.}$ will result in a net volume higher than the calculated gross volume.

Location: Table 1.3, worksheet “1-Stove”.

Cylindrical Net Firebox Volume

$$V_{fb} = \frac{1}{12^3}(r_{fb}^2 \times \pi \times h_{fb}) - V_{adj.} \quad \textit{(Eq. 2-2)}$$

where

r_{fb} is firebox radius (in),

and h_{fb} is firebox height (in).

Limits and ranges: firebox height and radius should be between 1 and 40 (in).

Location: Table 1.3, worksheet “1-Stove”.

B2.2 Fuel Load

B2.2.1 Target Log Length

For the cubic fireboxes the target length of the fuel log pieces is determined by:

$$L_{target} = \frac{5}{6} \times Max(h_{fb}, d_{fb}, w_{fb}) \quad \textit{(Eq. 2-3)}$$

And for the cylindrical fireboxes:

$$L_{target} = \frac{5}{6} \times Max(h_{fb}, r_{fb}) \quad \textit{(Eq. 2-4)}$$

Location: Table 2.1, worksheet “2-Fuel Load”.

B2.2.2 Log Loading Direction

If the firebox shape is cylindrical, then the loading direction is always East-West.

If the firebox shape is the loading direction depends on the firebox width and depth dimensions:

$$\begin{cases} firebox\ width \geq (firebox\ depth - 2) & \rightarrow \quad East - West \\ firebox\ width < (firebox\ depth - 2) & \rightarrow \quad North - South \end{cases}$$

Location: Table 2.1, worksheet “2-Fuel Load”.

B.2.2.3 Log Target Diameters

The wood logs for fuel are categorized into small pieces and large pieces. For each size category, a range of acceptable log diameter is calculated that is called the target range and it depends on the firebox volume and log size category through a set of second order equations. Two second order equations define the lower and upper bounds of the log diameter in each log size category. To derive each equation, we have defined three data points and then fitted a second order curve on them. The data points and equations are shown in Figure 2-1, Figure 2-2, Table 2-1, and Table 2-2.

Table B2-1 Upper and lower bounds of small log pieces as functions of firebox volume (V_{fb})

Firebox category	Firebox Vol.(ft3)	Log Diameter, lower bound (in)	Fitted Equation, lower bound	Log Diameter, upper bound (in)	Fitted Equation, lower bound
Small	0.80	2.2	$D = -0.136\ V_{fb}^2 + 0.882\ V_{fb} + 1.582$	3.1	$D = -0.159\ V_{fb}^2 + 1.195\ V_{fb} + 2.246$
Medium	2.00	2.8		4.0	
Large	3.00	3.0		4.4	

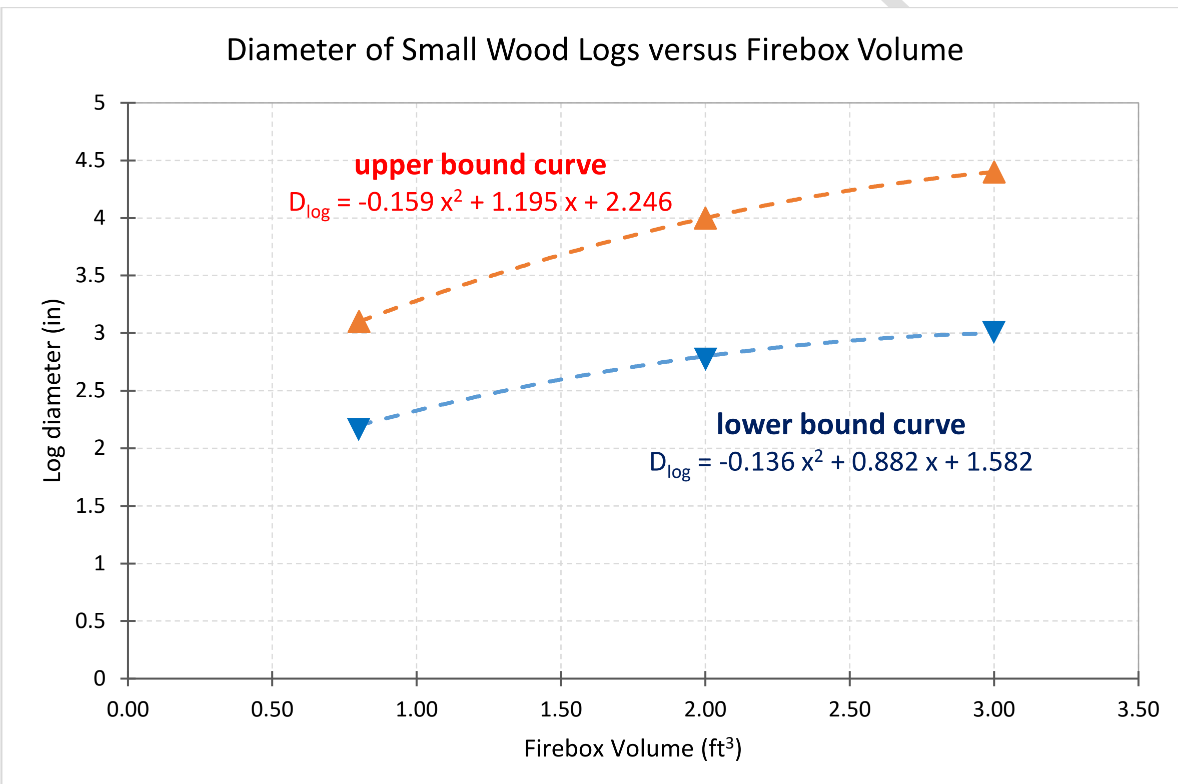


Figure B2-1 Upper and lower bounds of small log pieces as functions of firebox volume

Table B2-2 Upper and lower bounds of small log pieces as functions of firebox volume (V_{fb})

Firebox category	Firebox Vol.(ft3)	Log Diameter, lower bound (in)	Fitted Equation, lower bound	Log Diameter, upper bound (in)	Fitted Equation, lower bound
Small	0.80	3.1	D = -0.159 V_{fb}^2 + 1.195 V_{fb} + 2.245	4.5	D = 0.152 V_{fb}^2 + 0.242 V_{fb} + 4.209
Medium	2.00	4.0		5.3	
Large	3.00	4.4		6.3	

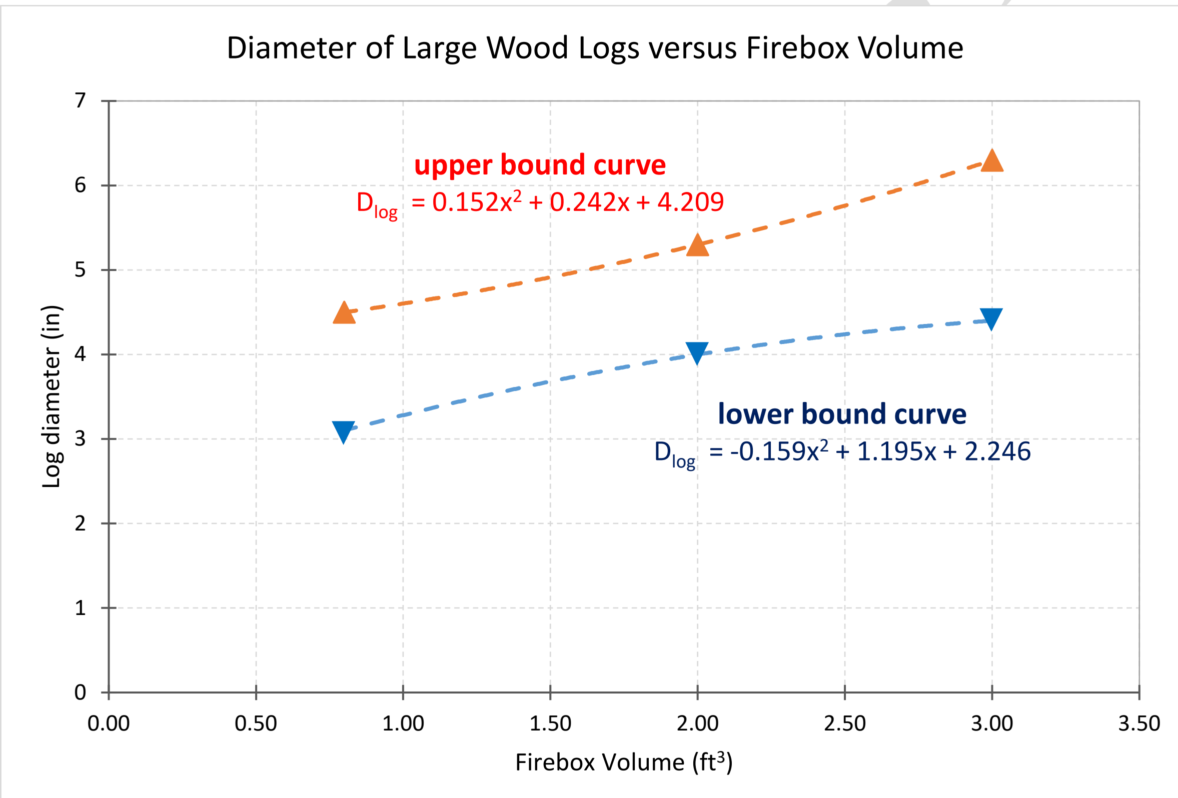


Figure B2-2 Upper and lower bounds of large log pieces as functions of firebox volume

Example of log target diameter calculations:

For a stove with a 2.100 (ft^3) firebox, the lower and upper bounds of log diameter for small pieces are:

$$D_{small\ log}^{lower} = -0.136 \times \left(\frac{2.100}{12^3}\right)^2 + 0.882 \times \left(\frac{2.100}{12^3}\right) + 1.582 = 2.83\ (in)$$

$$D_{small\ log}^{upper} = -0.159 \times \left(\frac{2.100}{12^3}\right)^2 + 1.195 \times \left(\frac{2.100}{12^3}\right) + 2.245 = 4.05\ (in)$$

And for the large pieces, the range of the target log diameter is:

$$D_{large\ log}^{lower} = -0.159 \times \left(\frac{2.100}{12^3}\right)^2 + 1.195 \times \left(\frac{2.100}{12^3}\right) + 2.245 = 4.05\ (in)$$

$$D_{large\ log}^{upper} = 0.152 \times \left(\frac{2.100}{12^3}\right)^2 + 0.242 \times \left(\frac{2.100}{12^3}\right) + 4.21 = 5.39\ (in)$$

Notice that the lower bound of the large log diameter, $D_{large\ log}^{lower}$, is always equal to the upper bound of the small log diameter $D_{small\ log}^{upper}$.

Location: All calculations for the lower and upper limits of the log diameters are done in the range Q2:V29 in the "2-Fuel Load" worksheet. These cells are hidden from the user and updated automatically. Only the results of the calculations are used in determining target range of the fuel piece weights.

B.2.2.4 Total Target Load Mass (wet-basis)

There are four loads in the IDC fueling protocol and the wet-basis total target weight of each load is calculated using the firebox net volume, V_{fb} according to the following formulas:

$$m_{L1}^{target} = m_{kindling}^{target} + m_{starter}^{target} \quad \textit{(Eq. 2-5)}$$

$$\text{For } V_{fb} < 1: \quad m_{kindling}^{target} = 1\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-6)}$$

$$\text{For } V_{fb} < 1: \quad m_{starter}^{target} = 3\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-7)}$$

$$\text{For } 1 \le V_{fb} \le 4: \quad m_{kindling}^{target} = 1 \times V_{fb}\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-8)}$$

$$\text{For } 1 \le V_{fb} \le 4: \quad m_{starter}^{target} = 3 \times V_{fb}\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-9)}$$

$$\text{For } 4 < V_{fb}: \quad m_{kindling}^{target} = 0.5 \times V_{fb}\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-10)}$$

$$\text{For } 4 < V_{fb}: \quad m_{starter}^{target} = 3.5 \times V_{fb}\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-11)}$$

$$m_{L2}^{target} = V_{fb} \times 7\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-12)}$$

$$m_{L3}^{target} = V_{fb} \times 5\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-13)}$$

$$m_{L4}^{target} = m_{L4\ small,wet}^{target} + m_{L4\ large,wet}^{target} \quad \textit{(Eq. 2-14)}$$

$$m_{L4\ small}^{target} = V_{firebox} \times 4\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-15)}$$

$$m_{L4\,large}^{target} = V_{firebox} \times 8\left(\frac{lb}{ft^3}\right) \quad \textit{(Eq. 2-16)}$$

where

m_{L1}^{target}, m_{L2}^{target}, m_{L3}^{target}, and m_{L4}^{target} are target wet-basis mass of loads 1, 2, 3, and 4, in pounds (lb), respectively,

and $m_{kindling}^{target}$, $m_{starter}^{target}$, $m_{L4\,small}^{target}$, and $m_{L4\,large}^{target}$ are target wet-basis mass for kindling, starter, small pieces of load 4, and large pieces of load 4, respectively.

All weights are in pounds (lb).

Location: Table 2.2, worksheet “2- Fuel Load”.

B.2.2.5 Total Target Load Mass Range (wet-basis)

The allowable (target) range of total mass of fuel in each load is calculated by considering ±5% tolerance of the total target load weight calculated in 2.2.4.

$$m_L^{target\,range} = [0.95 \times m_L^{target}\,, 1.05 \times m_L^{target}] \quad \textit{(Eq. 2-17)}$$

where L is the load name: kindling, starter, L1, L2, L3, L4 small, and L4 large.

Location: Table 3.1, worksheet “3.X-Run #X”.

B2.2.6 Minimum and Maximum Piece Mass (wet-basis)

Minimum and maximum mass of the pieces set the lower and upper acceptable limits for the wet-basis mass of the fuel pieces in each load.

For kindling pieces *(Eq. 2-18)*:

$$m_{kindling\,piece}^{min} = 0.1\ (lb)$$

$$m_{kindling\,piece}^{max} = 0.2\ (lb)$$

For starter pieces *(Eq. 2-19)*:

$$m_{starter\,piece}^{min} = 1.0\ (lb)$$

$$m_{starter\,piece}^{max} = 0.99 \times m_{L2\,piece}^{min}$$

where $m_{L2\,piece,wet}^{min}$ is the minimum wet-basis mass of the fuel pieces in L2.

For L2 pieces:

$$m_{L2\,piece}^{min} = \pi \times \frac{(D_{small\,log}^{lower})^2}{4} \times L_{target} \times \rho_{wood} \times \frac{1000}{12^3 \times 16.0185} \quad \textit{(Eq. 2-20)}$$

And the maximum wood piece weight is determined as the minimum of the following two expressions:

$$m_{L2\ piece}^{max} = Min\begin{cases} \pi \times \frac{(D_{small\ log}^{upper})^2}{4} \times L_{target} \times \rho_{wood} \times \frac{1000}{12^3 \times 16.0185} \\ 0.99 \times m_{L4\ large\ piece}^{max} \end{cases} \quad \textit{(Eq. 2-21)}$$

where

ρ_{wood} is the wood density in $\frac{kg}{m^3}$,

the $\frac{1000}{12^3 \times 16.0185}$ term is the coefficient to convert the density unit to $\frac{lb}{in^3}$,

and $m_{L4\ large\ piece}^{max}$ is the maximum wet-basis mass of the large pieces in Load 4.

For L3 pieces *(Eq. 2-22)*:

$$m_{L3\ piece}^{min} = 0.4 \times\ m_{L3,wet}$$

$$m_{L3\ piece}^{max} = 0.6 \times\ m_{L3,wet}$$

For L4 small pieces *(Eq. 2-23)*:

$$m_{L4\ small\ piece}^{min} =\ m_{L2\ piece,wet}^{min}$$

$$m_{L4\ small\ piece}^{max} =\ m_{L2\ piece,wet}^{max}$$

For L4 large pieces *(Eq. 2-24)*:

$$m_{L4\ large\ piece}^{min} = \pi \times \frac{(D_{large\ log}^{lower})^2}{4} \times L_{target} \times \rho_{wood} \times \frac{1000}{12^3 \times 16.0185} \quad \textit{(Eq. 2-25)}$$

$$m_{L4\ large\ piece}^{max} = \pi \times \frac{(D_{large\ log}^{upper})^2}{4} \times L_{target} \times \rho_{wood} \times \frac{1000}{12^3 \times 16.0185} \quad \textit{(Eq. 2-26)}$$

Location: Table 2.2, worksheet "2- Fuel Load".

B.2.2.7 Target Number of Wood Pieces per Load

The target number of wood pieces, n, in all loads, except for L3, is determined by dividing the total target mass of the load (see section 2.2.4) by the average of minimum and maximum mass of each wood piece (see 2.2.6) in that load.

For kindling:

$$n_{kindling}^{target} = Roundup(\frac{m_{kindling}^{target}}{Mean\left(m_{kindling\ piece}^{min}, m_{kindling\ piece}^{max}\right)}) \quad \textit{(Eq. 2-27)}$$

For starter:

$$n_{starter}^{target} = Roundup(\frac{m_{starter}^{target}}{Mean\left(m_{starter\ piece}^{min}, m_{starter\ piece}^{max}\right)}) \quad \textit{(Eq. 2-28)}$$

For L2:

$$n_{L2}^{target} = Roundup\left(\frac{m_{L2}^{target}}{Mean\left(m_{L2\ piece}^{min}, m_{L2\ piece}^{max}\right)}\right) \quad \textit{(Eq. 2-29)}$$

For L4 small pieces:

$$n_{L4\ small}^{target} = Roundup\left(\frac{m_{L4\ small}^{target}}{Mean\left(m_{L4\ small\ piece}^{min}, m_{L4\ small\ piece}^{max}\right)}\right) \quad \textit{(Eq. 2-30)}$$

For L4 large pieces:

$$n_{L4\ large}^{target} = Roundup\left(\frac{m_{L4\ large}^{target}}{Mean\left(m_{L4\ large\ piece}^{min}, m_{L4\ large\ piece}^{max}\right)}\right) \quad \textit{(Eq. 2-31)}$$

For Load 3, the target number of pieces is determined by the minimum of the following two expressions:

$$n_{L3}^{target} = Min\begin{cases} Roundup\left(\frac{m_{L3}^{target}}{Mean\left(m_{L3\ piece}^{min}, m_{L3\ piece}^{max}\right)}\right) \\ 3 \end{cases} \quad \textit{(Eq. 2-32)}$$

Which means the number of wood pieces in Load 3 cannot exceed 3.

Location: Table 2.2, worksheet "2- Fuel Load".

B2.3 Fueling

B.2.3.1 Total Loaded Fuel Mass (wet-basis)

The mass of each piece of wood in all loads (except for kindling pieces) should be measured and entered in Tables 3.2, 3.3, 3.4, 3.5, and 3.6. The total mass of the loaded fuel in each Load is equal to the sum of the mass of all pieced in that Load. For Load 1, the mass of the kindling pieces are added to the sum of the mass of the starter pieces. Table 3.1 in the Fuel Calculator shows the actual (i.e. measured in the lab) mass of the loaded fuel in each Load.

$$m_{L1} = m_{kindling} + (m_{L1,piece1} + m_{L1,piece2} + m_{L1,piece3} + \cdots) \quad \textit{(Eq. 2-33)}$$

$$m_{L2} = m_{L2,piece1} + m_{L2,piece2} + m_{L2,piece3} + \cdots \quad \textit{(Eq. 2-34)}$$

$$m_{L3} = m_{L3,piece1} + m_{L3,piece2} + m_{L3,piece3} \quad \textit{(Eq. 2-35)}$$

$$m_{L4} = m_{L4\ small} + m_{L4\ large} \quad \textit{(Eq. 2-36)}$$

$$m_{L4\ small} = m_{L4\ small,piece1} + m_{L4\ small,piece2} + m_{L4\ small,piece3} + \cdots \quad \textit{(Eq. 2-37)}$$

$$m_{L4\ large} = m_{L4\ large,piece1} + m_{L4\ large,piece2} + m_{L4\ large,piece3} + \cdots \quad \textit{(Eq. 2-38)}$$

All masses are in pound (lb).

Location: Tables 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6, worksheet "3.X-Run #X".

B.2.3.2 Moisture Content of a Wood Piece

On each piece of wood in all loads, expect kindling, the test operator should measure the moisture content (MC) four times, according to the IDC test procedure. MC of the piece is calculated by the average of three measurements.

$$MC_{piece} = \frac{MC_{pin\ 1} + MC_{pin\ 2} + MC_{pin\ 3}}{3} \quad \textit{(Eq. 2-39)}$$

If any of the MC pin values are missing, the MC_{piece} will not be calculated and displayed in the corresponding Excel cell. All MC values are in percentage.

Location: Tables 3.2, 3.3, 3.4, 3.5, and 3.6, worksheet "3.X-Run #X".

B2.3.3 Moisture Content of a Load

The average moisture content of an entire load is equal to the weighted average of all pieces in the load:

$$MC_{Lx} = \frac{\sum_1^{n_{Lx}} (m_{piece\ i} \times MC_{piece\ i})}{\sum_1^{n_{Lx}} (m_{piece\ i})} \quad \textit{(Eq. 2-40)}$$

where

MC_{Lx} is the average dry-basis moisture content of the load ($x = 1, 2, 3, and\ 4$),

and n_{Lx} is the actual number of pieces in the load x, and $m_{piece\ i}$ is the actual wet-basis weight of the wood piece.

The average MC value is calculated and displayed for small and large pieces of Load 4 separately, as well as for the entire load.

Location: The calculations are in column N, which is hidden, the values are shown in Tables 3.2, 3.3, 3.4, 3.5, and 3.6, worksheet "3.X-Run #X".

B.2.3.4 Moisture Content of a Run Entire Load

The average moisture content of the fuel for the entire run is equal to the weighted average of moisture contents of all four loads:

$$MC_{run} = \frac{\sum_{L1}^{L4} (m_L \times MC_L)}{\sum_{L1}^{L4} (m_L)} \quad \textit{(Eq. 2-41)}$$

Location: The calculation is in column N, which is hidden.

B2.3.5 Target Scale Range

Target scale range indicates the range of acceptable values that the scale reading should fall within at the end of each burning phase.

Actual scale reading at the start of the test and end of each phase are performed and entered in Table 3.9 by the lab operator where:

W_0^{scale} is the scale reading at the start of the test. Typically, this should be 0.0 (lb) after zeroing the scale,

W_{L1}^{scale} is the scale reading at the end of the Load 1,

W_{L2A}^{scale} is the scale reading at the end of the high burning phase of Load 2,

W_{L2}^{scale} is the scale reading at the end of Load 2,

W_{L3}^{scale} is scale reading at the end of Load 3,

and W_{L4}^{scale} is scale reading at the end of Load 4.

The scale reading should be done two times during Load 2, once at the end of the high burning phase (W_{L2A}^{scale}), and once at the end of the phase (W_{L2}^{scale}). The scale reading at the end of Load 4, W_{L4}^{scale}, indicates the weight of the remaining charcoal in the stove at the end of the test, plus the initial reading W_0^{scale}.

Target scale range for each Load has lower and upper bounds that are calculated by the following formulas.

For Load 1:

$$W_{L1,scale}^{lower} = 0.95 \times (m_{L2} \times 0.175) + W_0^{scale} \quad \textit{(Eq. 2-42)}$$

$$W_{L1,scale}^{upper} = 1.05 \times (m_{L2} \times 0.175) + W_0^{scale} \quad \textit{(Eq. 2-43)}$$

This means the target scale reading at the end of burning Load 1 is set to ±5% of the 17.5% of the actual wet-basis weight of Load 2.

For Load 2, high burning phase:

$$W_{L2A,scale}^{lower} = 0.95 \times (W_{L1}^{scale} + (m_{L2} \times 0.5)) + W_0^{scale} \quad \textit{(Eq. 2-44)}$$

$$W_{L2A,scale}^{upper} = 1.05 \times (W_{L1}^{scale} + (m_{L2} \times 0.5)) + W_0^{scale} \quad \textit{(Eq. 2-45)}$$

This means the target scale reading at the end of high burning phase of Load 2 is set to ±5% of the 50% of the actual wet-basis weight of Load 2 and the remaining of fuel from L1.

For Load 2, end of the phase:

$$W_{L2,scale}^{lower} = 0.95 \times (W_{L1}^{scale} + (m_{L2} \times 0.2)) + W_0^{scale} \quad \textit{(Eq. 2-46)}$$

$$W_{L2,scale}^{upper} = 1.05 \times (W_{L1}^{scale} + (m_{L2} \times 0.2)) + W_0^{scale} \quad \textit{(Eq. 2-47)}$$

This means the target scale reading at the end of high burning phase of L2 is set to ±5% of the 20% of the actual wet-basis weight of Load 2 and the remaining of fuel from L1. In other words, the target is to burn 80% of the Load 2 by the end of the phase.

For Load 3:

$$W_{L3,scale}^{lower} = 0.95 \times (W_{L2}^{scale} + (m_{L3} \times 0.1)) + W_0^{scale} \quad \textit{(Eq. 2-48)}$$

$$W_{L3,scale}^{upper} = 1.05 \times (W_{L2}^{scale} + (m_{L3} \times 0.1)) + W_0^{scale} \quad \textit{(Eq. 2-49)}$$

The target of fuel burning in Load 3 is 90% of the loaded fuel. Therefore, the target scale reading at the end of Load 3 is set to ±5% of the 10% of the actual wet-basis mass of Load 3 and the remaining of fuel from L2.

Similarly for Load 4:

$$W_{L4,scale}^{lower} = 0.95 \times (W_{L3}^{scale} + (m_{L4} \times 0.2)) + W_0^{scale} \quad \textit{(Eq. 2-50)}$$

$$W_{L4,scale}^{upper} = 1.05 \times (W_{L3}^{scale} + (m_{L4} \times 0.2)) + W_0^{scale} \quad \textit{(Eq. 2-51)}$$

The target is to burn 80% of the L4 loaded fuel. In Table 3.9, the only inputs from the user are the initial reading of the scale after zeroing, W_0, and scale readings at the end of each phase. The scale reading at the start of each phase before and after loading, and the target scale range are calculated automatically.

Location: Table 3.9, worksheet “3.X-Run #X”.

B2.3.6 Total Mass of the Burned Fuel

At the end of each phase, the total weight of the burned fuel (dry-basis), $m_{burned,L}^{db}$, is calculated and shown in Table 3.9. To calculate the weight of the burned dry fuel, the average moisture content of the load is used (see 2.3.3).

$$m_{burned,L1}^{db} = \frac{m_{L1}}{1+MC_{L1}} - (W_{L1}^{scale} - W_0^{scale}) \quad \textit{(Eq. 2-52)}$$

$$m_{burned,L2}^{db} = \frac{m_{L2}}{1+MC_{L2}} - (W_{L2}^{scale} - W_{L1}^{scale}) \quad \textit{(Eq. 2-53)}$$

$$m_{burned,L3}^{db} = \frac{m_{L3}}{1+MC_{L3}} - (W_{L3}^{scale} - W_{L2}^{scale}) \quad \textit{(Eq. 2-54)}$$

$$m_{burned,L4}^{db} = \frac{m_{L4}}{1+MC_{L4}} - (W_{L4}^{scale} - W_{L3}^{scale}) \quad \textit{(Eq. 2-55)}$$

$$m_{burned,run}^{db} = m_{burned,L1}^{db} + m_{burned,L2}^{db} + m_{burned,L3}^{db} + m_{burned,L4}^{db} \quad \textit{(Eq. 2-56)}$$

All weights are in pounds (lb). Conversion of the mass to the metric system units (kg):

$$m_{burned,L}^{db}(kg) = m_{burned,L}^{db} \times 0.453952 \quad \textit{(Eq. 2-57)}$$

Location: The calculations are done in column P, which is hidden, but the values are shown in Tables 3.1 and 3.9, worksheet “3.X-Run #X”.

Similarly, the total weight of the burned fuel (wet-basis), $m_{burned,L}^{wb}$ are calculated based on the mass of the burned fuel (dry-basis) from section 2.3.6:

$$m_{burned,L1}^{wb} = m_{burned,L1}^{db} \times (1 + MC_{L1}) \quad \textit{(Eq. 2-58)}$$

$$m_{burned,L2}^{wb} = m_{burned,L2}^{db} \times (1 + MC_{L2}) \quad \textit{(Eq. 2-59)}$$

$$m^{wb}_{burned,L3} = m^{db}_{burned,L3} \times (1 + MC_{L3}) \quad \textit{(Eq. 2-60)}$$

$$m^{wb}_{burned,L4} = m^{db}_{burned,L4} \times (1 + MC_{L4}) \quad \textit{(Eq. 2-61)}$$

$$m^{wb}_{burned,run} = m^{wb}_{burned,L1} + m^{wb}_{burned,L2} + m^{wb}_{burned,L3} + m^{wb}_{burned,L4} \quad \textit{(Eq. 2-62)}$$

All weights are in pounds (lb). Conversion to the metric system units (kg):

$$m^{wb}_{burned,L}(kg) = m^{wb}_{burned,L} \times 0.453952 \quad \textit{(Eq. 2-63)}$$

Location: The calculations are done in column M, which is hidden, but the values are shown in Tables 3.1 and 3.9, worksheet “3.X-Run #X”.

B2.3.7 Burn Rates

The dry-basis fuel burn rate, DBR, is determined by dividing the total mass of the burned dry fuel in kilograms by the duration of the burn and it can be calculated for a phase or the entire test run in $\frac{kg}{h}$:

$$DBR_L = \frac{0.453592 \times m^{db}_{burned,L}}{\Delta t_L} \quad \textit{(Eq. 2-64)}$$

where

L indicates either one of the four phases or the entire test run,

$m^{db}_{burned,L}$ is the total mass of the burned dry fuel in pounds from Section 2.3.6,

and Δt_L is the duration of the phase or entire test run in hours.

Location: The calculations are done in column Q, which is hidden, but the value of DBR_{run} is shown in Table 3.9, worksheet “3.X-Run #X”.

Similarly, the wet-basis fuel burn rate, WBR, is determined by dividing the total mass of the burned wet fuel in kilogram by the duration of the burn and it can be calculated for a phase or the entire test run in $\frac{kg}{h}$:

$$WBR_L = \frac{0.453592 \times m^{wb}_{burned,L}}{\Delta t_L} \quad \textit{(Eq. 2-65)}$$

B2.4 Gas Measurements and Calculations

The gas measurements include carbon monoxide (CO) and carbon dioxide (CO_2) and they are guided by EPA Methods 10 and 3A standards, modified as follows.

- CO and CO_2 gas measurements in the exhaust stack of the stove will be conducted using a **three-point sampling probe**, eliminating the need for a pre-test stratification test.
- The **CO analyzer range** will be set at **0-5%** for all test runs to capture the full range of emissions during the testing period. Due to the significant dynamic range of emissions from a wood stove over the course of a test run, not all measured values will necessarily fall within the required **20%-80% span** of the instrument.

- A **single range of 0-20%** will be used for **CO_2** for the same reason as stated above for the CO measurement.
- To prevent the loss of emissions data, **post-test drift calibration** will be performed only after completing the entire test run, within **24 hours ± 2 hours** of the pre-test calibration. **Calibration error limits for bias and drift** will comply with the method's requirements.

In each test run, the lab will measure and report CO and CO_2 concentrations in the stack. These are 1-min measurements that are considered “uncorrected” and expressed in molar percentage (%). The uncorrected values are then corrected using the post-run calibration procedure described in the following section. The corrected values are used to calculate emission factors, emission mass, emission rate, and per unit of output energy emissions.

B2.4.1 CO and CO_2 Corrected Concentrations

The observed CO and CO_2 measurements from the gas instrument are recorded and reported by the lab. The values are then corrected by the post- IDC run calibration procedure for CO and CO_2. The correction procedure requires adjustment by the daily zero offset from the zero-calibration gas pre-test and post-test followed by multiplication by a factor to correct for the average of pre-test and post-test span calibration results:

$$C_{CO} = \left(C_{CO,obs} - C_{CO,0}\right) \times \left(\frac{C_{CO,MA}}{C_{CO,M} - C_{CO,0}}\right) \quad \textit{(Eq. 3-66)}$$

where:

$C_{CO,obs}$ is the observed CO concentration measured on 1-min intervals during the test,

$C_{CO,0}$ is the average of pre- and post-test zero responses,

$C_{CO,MA}$ is the true concentration of the calibration gas,

and $C_{CO,M}$ is the average of pre- and post-test calibration responses.

All concentrations are expressed in the dry-basis molar percentage units (i.e. %vd). The above correction (the subtractor and the multiplier value) is calculated and presented.

A similar correction procedure and formula is used for CO_2 correction:

$$C_{CO_2} = \left(C_{CO_2,obs} - C_{CO_2,0}\right) \times \left(\frac{C_{CO_2,MA}}{C_{CO_2,M} - C_{CO_2,0}}\right) \quad \textit{(Eq. 3-67)}$$

The procedure for CO_2 correction follows the instructions in EPA Method 3A. The corrections are done for phase and total run average CO and CO_2 observation. When the corrected 1-min concentrations are ready, they are used to calculate emission metrics explained in the next sections.

The corrected concentrations of CO and CO_2 are calculated in molar (volumetric) percentage. They can be converted into PPM units by multiplying by 10,000:

$$C_{CO}(PPM) = C_{CO}(vd\%) \times 10{,}000 \quad \textit{(Eq. 3-68)}$$

$$C_{CO_2}(PPM) = C_{CO_2}(vd\%) \times 10{,}000 \quad \textit{(Eq. 3-69)}$$

B2.4.2 CO and CO$_2$ Emission Factors

The amount of CO and CO_2 emissions are normalized on the basis of the unit mass of the dry burned fuel ($\frac{g}{kg}$) or the unit of output energy ($\frac{lb}{MMBtu}$). These emission factors are crucial metrics to evaluate and compare emissions from wood stoves.

Mass-basis emission factors are the amounts of CO and CO_2 emissions (grams) per unit mass of the burned dry fuel ($\frac{g}{kg}$). These metrics are calculated for each phase and the entire IDC test run using the following equations:

$$EF_{CO} = \frac{\frac{CA}{12} \times C_{CO} \times 28}{C_{CO_2} + C_{CO}} \times 1000 \quad \textit{(Eq. 3-70)}$$

$$EF_{CO_2} = 44 \times \left(\frac{CA}{12} - \frac{EF_{CO}}{28}\right) \times 1000 \quad \textit{(Eq. 3-71)}$$

where

C_{CO} and C_{CO_2} are the average corrected concentrations as explained in section 3.1,

and CA is the carbon content of the dry fuel (% mass dry-basis).

Notice that for calculating mass-basis emission factors of CO and CO_2, the mass of the burned dry fuel, $m_{L,burned}^{db}$, or the total mass of the CO and CO_2 emissions are not required.

CO and CO_2 emissions should also be calculated per unit output energy of the stove. For these emission factors, first we need to calculate the total mass of the CO and CO_2 emissions for each phase and the entire test run, as explained in section 3.3. The total output energy, E_{out}, for each phase or the entire IDC run is estimated through the stove efficiency calculations, presented in section 4.4. With these two variables, energy-based emission factors are calculated by:

$$EF_{CO} = \frac{m_{CO}}{E_{out}} \quad \textit{(Eq. 3-72)}$$

$$EF_{CO_2} = \frac{m_{CO_2}}{E_{out}} \quad \textit{(Eq. 3-73)}$$

where EF_{CO} and EF_{CO_2} are CO and CO_2 emission mass per unit of output energy expressed in $\frac{g}{MJ}$.

These metrics are converted to the English system ($\frac{lb}{MMBtu}$) by:

$$EF_{CO}\left(\frac{lb}{MMBtu}\right) = EF_{CO} \times \frac{0.00220462}{947.817} \quad \textit{(Eq. 3-74)}$$

$$EF_{CO_2}\left(\frac{lb}{MMBtu}\right) = EF_{CO_2} \times \frac{0.00220462}{947.817} \quad \textit{(Eq. 3-75)}$$

B2.4.3 CO and CO$_2$ Emission Mass

From the mass-based emission factors, the total emitted masses of CO and CO_2 are calculated in grams:

$$m_{CO} = EF_{CO} \times m_{run}^{db} \quad \textit{(Eq. 3-76)}$$

$$m_{CO_2} = EF_{CO_2} \times m_{run}^{db} \quad \text{(Eq. 3-77)}$$

B2.4.4 CO and CO₂ Emission Rates

The rates of carbon monoxide and carbon dioxide emissions for a phase or an entire IDC test run are calculated by:

$$ER_{CO} = \frac{m_{CO}}{\Delta t} \quad \textit{(Eq. 3-78)}$$

$$ER_{CO_2} = \frac{m_{CO_2}}{\Delta t} \quad \textit{(Eq. 3-79)}$$

where Δt is the duration of the phase or entire IDC test run in hour (hr) and both emission rates are expressed in $\frac{g}{hr}$.

B2.5 Efficiency Calculations

This section outlines the calculations for method used to estimate cordwood stove efficiency. The IDC Total Combustion Calculation method is a form of the Stack Loss Method (SLM), in which the stove's useful heat output is determined by subtracting heat losses through the stack from the input fuel energy. The TCC method estimates overall thermal efficiency using the following equation:

$$\eta_{TCC} = 100\left(1 - \frac{e_l + e_c + e_s}{e_{in}}\right) \quad \textit{(Eq. 4-80)}$$

where

e_l is the latent heat loss, that is the energy required to vaporize the moisture content of the wood, which is carried out of the system via the stack.

e_c is the chemical heat energy loss, that is the energy lost in the form of unburned carbon-based combustion products, primarily carbon monoxide and hydrocarbons, that exit through the stack.

e_s is the sensible heat energy loss, that is the energy associated with raising the temperature (enthalpy) of combustion air and product gases from ambient room temperature to the stack gas temperature.

e_{in} is the input energy, that is the chemical energy content of the dry wood. This term is equal to the dry-basis higher heating value of the fuel (HHV).

All these energy items are expressed in terms of the amount of energy per unit mass of dry fuel such as $\frac{kJ}{kg}$. Therefore, the simplified IDC-TCC efficiency described in this section can be calculated without requiring the fuel burning rate (DBR) or the total burned fuel mass (m_{run}^{db}).

B2.5.1 Latent Heat Loss

The latent heat loss per kilogram of burned dry fuel, e_l, is calculated by:

$$e_l = m_{H_2O,v} \times \Delta H_{vap} \quad \textit{(Eq. 4-81)}$$

where

ΔH_{vap} is the enthalpy of water vaporization at 20 (°C), equal to 2442 ($\frac{kJ}{kg}$),

and $m_{H_2O,v}$ is the mass of the evaporated water in stack gas per unit mass of the burned dry fuel ($\frac{kg}{kg}$) and it is calculated by:

$$m_{H_2O,v} = 9 \times HY + MC_{db} \quad \textit{(Eq. 4-82)}$$

where

HY is the hydrogen content of the dry fuel (mass % dry-basis),

and MC_{db} is the moisture content of the fuel (% dry-basis)

B2.5.2 Chemical Heat Loss

In the IDC-TCC method assumes that all unburned carbon products in the stack gas are a linear function of average CO concentration, and it is calculated by:

$$C_{TCC} = CF_{TCC} \times C_{CO} \quad \textit{(Eq. 4-83)}$$

where

C_{TCC} is the estimated concentration of combustible carbon (molar %),

C_{CO} is the corrected carbon monoxide concentration in the stack gas (molar %) as described in section 3.1,

and CF_{TCC} is the adjustment coefficient called Carbon Factor.

For modern cordwood stove technologies, $CF_{TCC} = 1$, which means the amount of unburned hydrocarbon products is negligible.

From C_{TCC} we calculate the theoretical concentration of carbon dioxide, $C_{CO_{2,si}}$, under the assumption that the combustion is perfect:

$$C_{CO2,si} = C_{CO_2} + C_{TCC} \quad \textit{(Eq. 4-84)}$$

where C_{CO_2} is the corrected carbon dioxide concentration in the stack gas (molar %) as described in section 3.1,

The chemical energy loss per unit mass of the burned dry fuel, e_c ($\frac{kJ}{kg}$), is calculated by:

$$e_c = \frac{CA}{12} \times \frac{C_{TCC}}{C_{CO_{2,si}}} \times LHV_{UCP} \quad \textit{(Eq. 4-85)}$$

where

CA is the carbon content of the dry fuel (% mass dry-basis),

and LHV_{UCP} is the average lower heating value of the unburned carbon products in the stack per mole, equal to 400,000 ($\frac{kJ}{kmol}$)

B2.5.3 Sensible heat loss

The sensible heat loss, e_s, includes three components: (1) enthalpy change of the dry combustion products and combustion air, (2) enthalpy change of the water content of the combustion air, and (3) enthalpy change of the vaporized moisture content of the fuel. The change of enthalpy is due to the temperature difference between the room and the stack gases.

To calculate the change of enthalpy of dry combustion products, first we calculate the mass of dry stack gas per unit mass of dry burned fuel, m_{ds} $(\frac{kg}{kg})$:

$$m_{ds} = \frac{CA}{12 \times C_{CO_{2,si}}} \times MW_{ds,TCC} \quad \textit{(Eq. 4-86)}$$

where $MW_{ds,TCC}$ $\left(\frac{g}{mol}\right)$ is the species-averaged molecular weight of the dry stack gas and it is calculated by:

$$MW_{ds,TCC} = 44 \times C_{CO_{2,si}} + 32 \times C_{O_{2,si}} + 28 \times C_{N_2} \quad \textit{(Eq. 4-87)}$$

where $C_{O_{2,si}}$ is the concentration of oxygen in the stack gas (molar %), under the assumption that all unburned carbon products are combusted, and it is calculated by:

$$C_{O_{2,si}} = 20.947 - C_{CO_{2,si}} \quad \textit{(Eq. 4-88)}$$

and C_{N_2} is the concentration of nitrogen in air (molar %), equal to 78.084%

We also approximate the average constant-pressure specific heat of the dry stack gas, in $\frac{kJ}{kg.K}$ by:

$$C_{p,ds} = 1.003 + 3.488 \times 10^{-5} \times (T_s - T_a) + 2.036 \times 10^{-7} \times (T_s - T_a)^2 \quad \textit{(Eq. 4-89)}$$

where T_a is ambient (lab) air average temperature and T_s is the stack gas average temperature, both expressed in °C units.

The sensible heat loss per unit mass of the burned dry fuel is calculated by:

$$e_s = \left(\left(m_{ds} \times C_{p,ds}\right) + \left(m_{H_2O,s} \times C_{p,H_2O}\right)\right) \times (T_s - T_a) \quad \textit{(Eq. 4-90)}$$

In this formula the term $\left(m_{ds} \times C_{p,ds}\right)$ captures the first component of the sensible heat loss, and $\left(m_{H_2O} \times C_{p,H_2O}\right)$ captures the second and third components, $C_{p,H_2O} = 1.9$ $\left(\frac{kJ}{kg\ K}\right)$ is the specific heat of the water vapor, and $m_{H_2O,s}$is the total mass of water in the stack gas per unit mass of the burned dry fuel. It is calculated as the sum of the vaporized water from fuel, $m_{H_2O,v}$, from section 4.1, and moisture content of the combustion air, $m_{H_2O,a}$ $(\frac{kg}{kg})$:

$$m_{H_2O,s} = m_{H_2O,v} + m_{H_2O,a} \quad \textit{(Eq. 4-91)}$$

$$m_{H_2O,a} = \omega_a \times \frac{AFR \times 18}{29} \quad \textit{(Eq. 4-92)}$$

where AFR $\left(\frac{kg}{kg}\right)$ is the dry air-to-fuel ratio, and ω_a $\left(\frac{kg}{kg}\right)$ is the water-air mixing ratio (mass of water vapor per unit mass of ambient dry air). The air-to-fuel ratio is calculated by:

$$AFR = m_{ds} - (1 + m_{H_2O,v} + MC_{db}) \quad \textit{(Eq. 4-93)}$$

The value of ω_a is a function of air temperature, relative humidity, and ambient pressure. At the standard condition of 25 (°C) and 1 atm (29.92 in Hg) ω_a is between 0.004 and 0.02 (kg/kg) for various relative humidity levels. Because the effect of ω_a on thermal efficiency of the stove is not significant, we can take a default value of $\omega_a = 0.015$, which corresponds to the ambient relative humidity, RH_a, of 60% under the standard condition.

If the lab ambient pressure, temperature, and relative humidity changed drastically from the above condition, the more accurate value of mixing ratio can be calculated by

$$\omega_a = \frac{0.622 \times 6.112 \times e^{\left(\frac{17.67 \times T_a}{T_a + 245.5}\right)} \times RH_a}{P_a - 6.112 \times e^{\left(\frac{17.67 \times T_a}{T_a + 245.5}\right)} \times RH_a} \quad \textit{(Eq. 4-94)}$$

Where P_a is the ambient (lab) air pressure in millibars and at the sea level it is 1013.25 (mb). This formula is derived from saturation water pressure calculations presented by Bolton (1980).

According to NYSERDA IDC Test Protocol, efficiency calculations should include all test run data for the overall run efficiency. We also calculate phase efficiencies for L2, L3, and L4 individually.

B2.5.4 Output Energy

The amount of the useful output heat energy per kilogram of dry burned fuel ($\frac{kJ}{kg}$) is calculated by:

$$e_{out} = \eta_{TCC} \times e_{in} \quad \textit{(Eq. 4-95)}$$

To convert it to the English system units ($\frac{Btu}{lb}$):

$$e_{out}\left(\frac{Btu}{lb}\right) = e_{out} \times 0.4299 \quad \textit{(Eq. 4-96)}$$

By multiplying e_{out} by the total mass of the dry burned fuel, m_{run}^{db}, the total amount of energy output is calculated in MJ units:

$$E_{out} = e_{out} \times m_{run}^{db} \times 10^{-3} \quad \textit{(Eq. 4-97)}$$

And it is converted to the English system units ($MMBtu$):

$$E_{out}(MMBTu) = \frac{E_{out}}{1055.1} \quad \textit{(Eq. 4-98)}$$

B2.6 Dilution Tunnel Measurements

Dilution tunnel calculations are performed based on the EPA Method 2 approach for stack gas and are summarized in this section.

B2.6.1 Tunnel Velocity

Per Section 6.7 of EPA Method 2, the lab uses a standard pitot tube as defined in. The baseline coefficient, C_P, for such standard pitot tube is 0.99±0.01. The average diluted stack gas velocity over one minute measurement, V_t, is calculated by Eq. 2-7 in EPA Method 2 in the $(\frac{ft}{s})$ units:

$$V_t = K_P \times C_{pitot} \times \sqrt{\frac{T_{t(abs)}}{P_{t(abs)} \times MW_{t(wet)}}} \times \sqrt{\Delta P_t} \quad \textit{(Eq. 5-99)}$$

where:

C_{pitot} is a dimensionless pitot tube baseline coefficient, equal to 0.99±0.01 for a standard pitot tube,

$MW_{t(wet)}$ is the molecular weight of diluted wet stack gas, $(\frac{\mathrm{g}}{\mathrm{mol}})$ or $\left(\frac{lb}{lbmol}\right)$ for the Metric or English system.

and ΔP_t is the velocity head of the diluted stack gas, averaged over one minute in $in.Hg$,

K_P is the velocity equation constant, and it is equal to:

$$K_P = 85.49 \; \frac{ft}{s} \left[\frac{(lb/lbmol)(in.Hg)}{(°R)(in\; H_2O)}\right]^{\frac{1}{2}} \quad \textit{(Eq. 5-100)}$$

$T_{t(abs)}$ is the absolute diluted stack gas temperature in $°R$. If the lab logs this variable in °F it should be converted to °R by

$$T_{t(abs)}(°\mathrm{R}) = TNL\_T(°\mathrm{F}) + 459.67 \quad \textit{(Eq. 5-101)}$$

and $P_{t(abs)}$ is the absolute diluted stack pressure in $(in.Hg)$ and it is equal to:

$$P_{t(abs)} = P_a + P_t \quad \textit{(Eq. 5-102)}$$

where P_a is the barometric pressure (in Hg) at measurement site and P_t is diluted stack gas static pressure, Pt is expressed in $in\frac{H20}{13.6}$ to convert to in Hg for Pt (abs).

To correct for the difference between the traverse and center point velocity values, the lab uses a correction factor, F_P, calculated by:

$$F_P = \frac{V_{s(travese)}}{V_{s(center)}} \quad \textit{(Eq. 5-103)}$$

The lab must measure velocity values and calculates F_P before each IDC test run and enters that information into the data logger system to correct the V_t value

B2.6.2 Tunnel Flow

Following section 12.7 in EPA Method 2, the volumetric flow rate of the diluted stack gas is reported as wet standard cubic feet per minute (SCFM), averaged over one-minute intervals:

$$Q_{t(wet)} = 60 \times V_t \times A_t \left[\frac{528 * P_{t(abs)}}{T_{t(abs)} \times 29.92}\right] \quad \textit{(Eq. 5-104)}$$

Where

V_s is the one-minute average of the diluted stack gas velocity explained in section 5.1,

A_s is the cross -sectional area of the dilution tunnel in ft^2,

and $528\ (°R)$ and $29.92(in.Hg)$ are standard temperature and pressure values.

Tunnel flow rate is calculated and recorded at 1-minute intervals. After each test run, 10-minute rolling average of the flow, denoted by $Q_{t(wet)}^{10-min}$, should be calculated for QA/QC purposes, as explained in Appendix B-1. Method 5G-X .

B2.6.3 Sampling Ratio Determination

In NYSERDA Method 5G-X, Sampling Ratio (SR) is calculated instead of the proportionality ratio, as explained in section 12.7 of the method. First, the Initial Sampling Ratio (SR_0) should be calculated by dividing the initial dilution tunnel flow rate, $Q_{0,t(wet)}$, by the initial filter sampling flow rate, $Q_{0,f(wet)}$:

$$SR_0 = \frac{Q_{0,t(wet)}}{Q_{0,f(wet)}} \quad \textit{(Eq. 5-105)}$$

Similar calculation should be done for every minute of the test:

$$SR_i = \frac{Q_{i,t(wet)}}{Q_{i,f(wet)}} \quad \textit{(Eq. 5-106)}$$

The sampling rations calculated here are used for quality control and validation of Method 5G-X measurements, as explained in Appendix B-1. Method 5G-X .

B2.7 Particulate Matter Measurements

B2.7.1 Manual Filter-Based Method

The filter-based PM measurement is performed based on Method 5G-X (a modified version of EPA 5G-3) or ASTM E2515 standards. Because the manual filter pulls only obtains a single value. The filter PM measurements only obtain PM data on a total IDC run basis. This method compares collected emissions from two Teflon coated glass fiber filter sample trains after the filters are weighed gravimetrically. Detailed calibration, calculations, and QA/QC procedures are described in the Method 5G-X. Determining emission rates requires the use of wet tunnel flow, the calculation of which is shown in section 5.2.

B2.7.1.1 Filter Blank Validity Check

A single set of field blanks (front and back) are collected for each test run according to the instructions in Section 8.10.3 of Method 5G-X. The collected PM on these field blanks should not be subtracted from the PM catch on the testing filter weights. The filed blanks are used for method QA/QC as explained in Appendix B-1. Method 5G-X . In addition, the greater of twice the range of field blanks or 3 times the standard deviation from a set of certification tests shall be reported as the method limit of detection (LOD) for mass measurement.

B2.7.1.2 5G-X PM Mass Catch and Concentration

The total amount of particulate matter catch is measured through two separate filter trains according to the Method 5G-X procedure. This includes adding any residue stuck to the o-ring to the final recorded mass (see Method 5G-X Section 8.12.2.3). In the method, the net mass of the PM catch is designated as m_n expressed in milligrams. In this document we use m_n^{5GX} to refer to it. The lab reports the total PM mass catch on two filter trains, $m_n^{5GX(a)}$ and $m_n^{5GX(b)}$ in milligrams (mg).

PM mass catch values are converted to PM concentrations ($\frac{g}{m^3}$) following the equation in section 12-5 of Method 5G-X:

$$C_{PM}^{5GX(a)} = \frac{m_n^{5GX(a)}}{V_{f(std)}^{5GX(a)} \times 1000} \quad \textit{(Eq. 6-107)}$$

$$C_{PM}^{5GX(b)} = \frac{m_n^{5GX(b)}}{V_{f(std)}^{5GX(b)} \times 1000} \quad \textit{(Eq. 6-108)}$$

where $V_{f(std)}^{5GX(a)}$ and $V_{f(std)}^{5GX(b)}$ are the total volume of wet gas measured by the mass flow meter over the sampling period from filter train a and b. These volumes are corrected to the standard conditions of 20 °C and 1 atm expressed in cubic meters (m^3). The lab should report $V_{f(std)}^{5GX(a)}$ and $V_{f(std)}^{5GX(b)}$ in both liters (l) and cubic feet per minute (ft^3). To convert them to cubic meters we use the following equations:

$$V_{m(std)}^{5GX} = \frac{V_{m(std)}^{5GX}(l)}{1000} \quad \textit{(Eq. 6-109)}$$

$$V_{m(std)}^{5GX} = \frac{V_{m(std)}^{5GX}(ft^3)}{0.02832} \quad \textit{(Eq. 6-110)}$$

B2.7.1.3 5G-X PM Emission Rate

The PM emission rate in ($\frac{g}{h}$) for each filter train is calculated by:

$$ER_{PM}^{5GX(a)} = C_{PM}^{5GX(a)} \times Q_{t(wet)} \times 2.814 \times 10^{-5} \times 60 \quad \textit{(Eq. 6-111)}$$

$$ER_{PM}^{5GX(b)} = C_{PM}^{5GX(b)} \times Q_{t(wet)} \times 2.814 \times 10^{-5} \times 60 \quad \textit{(Eq. 6-112)}$$

The emission rate for the entire IDC test run is the average of the two trains:

$$ER_{PM}^{5GX} = \frac{ER_{PM}^{5GX(a)} + ER_{PM}^{5GX(b)}}{2} \quad \textit{(Eq. 6-113)}$$

where $Q_{t(wet)}$ is the average flow rate of diluted stack gas in the tunnel during the IDC test run expressed in dry standard cubic feet (see section 5.2).

The relative difference, %D, of the PM emission rate, ΔER_{PM}^{5GX}, is defined as the absolute difference between two measurements from trains a and b, divided by their average, expressed as a percentage (%):

$$\Delta ER_{PM}^{5GX} = \frac{ABS(ER_{PM}^{5GX(a)} - ER_{PM}^{5GX(b)})}{ER_{PM(5GX)}} \times 100 \quad \textit{(Eq. 6-114)}$$

The relative difference metric ,ΔER_{PM}^{5GX}, is used for data quality control and measurement validity, as explained in Appendix B-1. Method 5G-X .

B2.7.1.4 5G-X PM Emission Mass

The total mass of the PM emissions in grams, m_{PM}^{5GX}, over the entire IDC run is calculated by:

$$m_{PM}^{5GX} = ER_{PM}^{5GX} \times \frac{\Delta t_{run}}{60} \quad \textit{(Eq. 6-115)}$$

where $ER_{PM}^{5GX}\ \left(\frac{g}{h}\right)$ is the average PM emission rate calculated in section 6.1.3 and Δt_{run} is the total duration of the IDC test run in minutes.

B2.7.1.5 5G-X PM Emission Factors

PM emissions are normalized based on the unit mass of the dry burned fuel ($\frac{g}{kg}$) or the unit of output energy ($\frac{g}{MJ}$ or $\frac{lb}{MMBtu}$). These emission factors are crucial metrics to evaluate and compare emissions from wood stoves.

The mass-based PM emission factor from filter-pull method is calculated for the entire IDC test run in grams per kilogram unit ($\frac{g}{kg}$) by dividing the total mass of the PM emissions, m_{PM}^{5GX} (section 6.1.4), by the dry-basis mass of the burned fuel, m_{run}^{db} (section 2.3.6):

$$EF_{PM}^{5GX} = \frac{m_{PM}^{5GX}}{m_{run}^{db}} \quad \textit{(Eq. 6-116)}$$

PM emission factor should also be calculated per unit output energy of the stove. The total output energy, E_{out}, for the entire IDC run is estimated through the stove efficiency calculations, presented in section 4.4. Using the output energy, PM emissions per unit of output energy are calculated by:

$$EF_{PM}^{5GX} = \frac{m_{PM}^{5GX}}{E_{out}} \quad \textit{(Eq. 6-117)}$$

where EF_{PM}^{5GX} is expressed in $\frac{g}{MJ}$ units. To convert it to the English system units ($\frac{lb}{MMBtu}$):

$$EF_{PM}^{5GX}\left(\frac{lb}{MMBtu}\right) = EF_{PM}^{5GX} \times \frac{0.00220462 \times 10^{6}}{947.817} \quad \textit{(Eq. 6-118)}$$

B2.7.2 TEOM Continuous PM Measurement

The second method of measuring PM emissions in the IDC testing is continuous PM measurement by using a Thermo 1405-D to obtain continuous PM measurements over 1-minute intervals. The TEOM operation protocol, calibration, QC/QA, and calculations are described in the NYSERDA TEOM Standard Operation Procedures (SOP) document from which we present some of the calculations in this section.

The 1405-D Dual channel TEOM instrument measures and reports PM emissions through two independent channels. In the TEOM data logging system, the left channel is label "PM-2.5", and the right channel is labeled "PM-Coarse". In this document we refer to these as channel a ("PM-2.5") and channel b ("PM-Coarse").

The workflow of processing, validating, aggregating, and reporting TEOM data is shown in Figure 6-1. At the end of each IDC test rung the data will be downloaded from the TEOM. The TEOM saves the data with the following filename format: *"1405Annnnnnnnn_yyyy-m(m)-d(d)_h(h)-m(m)-s(s).csv"* (leading zeros are suppressed) where *nnnnnnnnn* is the instrument serial number, and the date-time are when the data were downloaded, not the date of the test. In the csv file there are data columns for concentration, total mass, flow rate, air tube temperature, filter load, filter pressure, noise, and frequency for both channels. Also, there are other data columns such as time stamp, operating mode, case temperature, and cap temperature that are not channel specific.

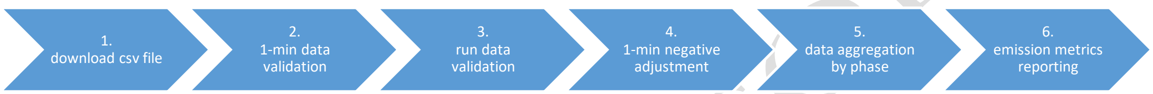


Figure 6-3 Workflow of TEOM data processing and reporting

Other steps of the TEOM data processing and reporting workflow are described in the following sections.

B.2.7.2.1 TEOM 1-min Data Validation

Processing and reporting TEOM data includes data validation at two separate steps, as displayed in Figure 6-1. For the first part (step 2 in Figure 6-1), validation is performed manually on 1-min PM concentration data points. To facilitate and document this step NESCAUM has prepared a data processing and validation spreadsheet named "NYSERDA TEOM data template".

For each minute of the IDC test, the 1045-D Dichotomous TEOM records two raw PM concentration values: $C_{PM}^{TEOM(a),raw}$ ("PM-2.5 raw MC", the left channel) and $C_{PM}^{TEOM(b),raw}$ ("PM-Coarse raw MC", the right channel). The user should transfer the downloaded data from the csv file into the data processing and validation spreadsheet, following the instructions described in the spreadsheet (sheet 'Revisions'). According to the NYSERDA TEOM SOP document, raw PM concentration data points are considered valid only if all the criteria listed below are met:

1) Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm for 1 lpm)
2) Operating mode (not system status): 3 or 4
3) Noise: 3-minute tunnel PM running average of (100 x noise / concentration) is < 0.20 µg
4) Case temperature: no higher than 32.2 °C (90 °F).
5) Concentration is not 0.00
6) Total Mass is not 0.00
7) Concentration is different from the preceding 1-minute interval.
8) For a valid minute of test data, at least one channel of Tunnel PM data must be valid.

Invalid data points must be manually removed as described in the data processing and validation spreadsheet instructions. Data that might be of questionable quality but pass all the validation criteria should be retained. If they are influential at the phase data level, they should be flagged for possible review. After identifying all invalid data points and removing them, for each 1-min interval there must be at least a valid concentration data. If both are invalid, then that minute's TEOM measurement is invalid.

The data collected on the channel labeled "PM-2.5 raw MC" ($C_{PM}^{TEOM(a),raw}$) does not require any modification after validation. However, data from the "PM-Coarse raw MC" $C_{PM}^{TEOM(b),raw}$ channel must be corrected using the following equation (see NYSERDA TEOM SOP for more details):

$$C_{PM,unadj.}^{TEOM(a)} = C_{PM}^{TEOM(a),raw} \qquad \textit{(Eq. 6-119)}$$

$$C_{PM,unadj.}^{TEOM(b)} = C_{PM}^{TEOM(b),raw} \times \frac{16.667}{Q_{TEOM(b)}} \qquad \textit{(Eq. 6-120)}$$

where

$C_{PM,unadj.}^{TEOM(a)}$ and $C_{PM,unadj.}^{TEOM(b)}$ are validated unadjusted PM concentrations from two TEOM channels in $\frac{\mu g}{m^3}$. These are called unadjusted because the negative values are not replaced with zero (see below for more details).

$C_{PM}^{TEOM(a),raw}$ and $C_{PM}^{TEOM(b),raw}$ are the raw PM concentrations from two TEOM channels in $\frac{\mu g}{m^3}$,

and $Q_{TEOM(b)}$ is the flow rate of the TEOM coarse channel (channel b) in liters per minute ($\frac{l}{m}$). The nominal value of $Q_{TEOM(b)}$ is equal to $1\left(\frac{l}{m}\right)$, but if it is different, the user must set it in the TEOM data processing template spreadsheet.

Calculations in equation 6-13 and 6-14 are performed for each minute of the test inside the TEOM data processing spreadsheet. The concentrations are called unadjusted because the negative values are not replaced with zero. Adjustment of the negative values are described in Section 6.2.3.

B.2.7.2.2 TEOM Run Data Validation

In addition to checking and validating data at 1-min intervals, TEOM data must be validated at the run level (step 3 in Figure 6-1).

First, with the valid 1-min TEOM PM concentration values, we calculate the relative difference, %D, or $\Delta\bar{C}_{PM,unadj.}^{TEOM}$ (%) by:

$$\Delta\bar{C}_{PM,unadj.}^{TEOM} = \frac{ABS(\bar{C}_{PM,unadj.}^{TEOM(a)} - \bar{C}_{PM,unadj.}^{TEOM(b)})}{\frac{\bar{C}_{PM,unadj.}^{TEOM(a)} + \bar{C}_{PM,unadj.}^{TEOM(b)}}{2}} \times 100 \qquad \textit{(Eq. 6-121)}$$

Where $\bar{C}_{PM,unadj.}^{TEOM(a)}$ and $\bar{C}_{PM,unadj.}^{TEOM(b)}$ are average of validated unadjusted TEOM PM concentrations over the entire IDC run. The value of $\Delta\bar{C}_{PM,unadj.}^{TEOM}$ must be no more than 7.5% for an IDC test run to be valid, according to NYSERDA TEOM SOP.

Second, with the validated 1-min TEOM data, the total number of minutes with valid (non-missing) measurements should be determined. For each 1-min interval there must be at least a valid concentration data. If both are invalid, then that minute's TEOM measurement is invalid. The count of valid minutes is referred to as TEOM valid time denoted by Δt^{TEOM}, and it is determined for each phase and the entire test run. The TEOM valid time is typically less than or equal to the corresponding test time Δt. The ratio of TEOM valid time to the total test time serves as another data validity criterion. Specifically, any burn phase or full test run with less than 85% valid TEOM data coverage is considered invalid for purposes of PM emission reporting based on TEOM data.

The percentage of valid TEOM time for each phase or the full test run is calculated as:

$$\theta_L^{TEOM} = 100 \times \frac{\Delta t_L^{TEOM}}{60 \times \Delta t_L} \quad \textit{(Eq. 6-122)}$$

where

θ_L^{TEOM} denotes the TEOM data coverage of burn phase L or the entire IDC run

Δt_L^{TEOM} is the duration of TEOM valid data burn phase L or the entire IDC run in minutes

and Δt_L is the duration of burn phase L or the entire IDC run in hours.

Any burn phase and a test run with $85\% \leq \theta^{TEOM}$ is considered valid in terms of the TEOM valid data coverage, as explained in NYSERDA TEOM SOP.

Both steps of TEOM data validation are described in Appendix B-2. TEOM Data QC.

B2.7.2.3 PM Concentration Adjustment

In the TEOM PM measurement process negative concentration data can occur when there is substantial mass on the TEOM filter and PM emissions become very low, typically near the end of a burn phase. The filter can lose mass when this occurs, and that results in negative PM being reported. After data validation, concentration data points should be adjusted for negative values (step 4 in Figure 6-1). NESCAUM has prepared another spreadsheet template ("NYSERDA TEOM grams per phase") to automate, document, and facilitate concentration data adjustment and aggregation.

In the data adjustment and aggregation spreadsheet template, any 1-minute data less than zero is set to zero, otherwise the adjusted and unadjusted concentrations are the same:

$$if\ C_{PM,unadj.}^{TEOM(a)} \geq 0 \rightarrow \quad C_{PM}^{TEOM(a)} = C_{PM,unadj.}^{TEOM(a)} \quad \textit{(Eq. 6-123)}$$

$$if\ C_{PM,unadj.}^{TEOM(a)} < 0 \rightarrow \quad C_{PM}^{TEOM(a)} = 0 \quad \textit{(Eq. 6-124)}$$

$$if\ C_{PM,unadj.}^{TEOM(b)} \geq 0 \rightarrow \quad C_{PM}^{TEOM(b)} = C_{PM,unadj.}^{TEOM(b)} \quad \textit{(Eq. 6-125)}$$

$$if\ C_{PM,unadj.}^{TEOM(b)} < 0 \rightarrow \quad C_{PM}^{TEOM(b)} = 0 \quad \textit{(Eq. 6-126)}$$

where $C_{PM}^{TEOM(a)}$ and $C_{PM}^{TEOM(b)}$ are adjusted TEOM PM concentrations in $\frac{\mu g}{m^3}$ units.

The final TEOM PM concentration value is the average of two channels, if at least one of the channels has a valid measurement. During an IDC test it is possible that one or both TEOM channels are missing measurements. It can happen during the TEOM filter change or when the TEOM operator identifies an invalid data point (see section 6.2.1). In those cases, if both channels are missing data, then TEOM PM concentration is considered missing. When both channels have valid measurements:

$$C_{PM}^{TEOM} = \frac{C_{PM}^{TEOM(a)} + C_{PM}^{TEOM(b)}}{2} \quad \textit{(Eq. 6-127)}$$

when only one channel presents a valid data point C_{PM}^{TEOM} is equal to that value.

The adjusted TEOM PM emission is used to calculate and report emission metrics. We also calculate unadjusted TEOM PM emission metrics for the purpose of comparison only, and not for reporting purposes. To determine the average unadjusted TEOM PM concentration, we follow the same steps. If both channels have valid data points, we take the average of the channels:

$$C_{PM,unadj}^{TEOM} = \frac{C_{PM,unadj}^{TEOM(a)} + C_{PM,unadj}^{TEOM(b)}}{2} \quad \textit{(Eq. 6-128)}$$

when only one channel presents a valid data point $C_{PM,unadj.}^{TEOM}$ is equal to that value and when both channels are missing valid data, $C_{PM,unadj.}^{TEOM}$ is also considered missing.

B2.7.2.4 TEOM PM Emission Rate

The PM emission rate based on the TEOM measurements is calculated using the adjusted TEOM concentration and the diluted stack gas flow rate in the tunnel for every minute of the test. The emission rate for the i^{th} minute is given by:

$$ER_{PM,i}^{TEOM} = C_{PM,i}^{TEOM} \times Q_{t(wet),i} \times 2.814 \times 10^{-8} \times 60 \quad \textit{(Eq. 6-129)}$$

where

$ER_{PM,1min}^{TEOM}$ is expressed in grams per hour ($\frac{g}{h}$) and it is the TEOM PM emission rate over 1 minute interval,

$C_{PM,i}^{TEOM}$ is the adjusted TEOM PM concentration ($\frac{\mu g}{m^3}$) at the i^{th} minute as explained in section 6.2.3,

and $Q_{t(wet),i}$ is the average flow rate of diluted stack gas in the tunnel at the i^{th} minute expressed in wet standard cubic feet as explained in section 5.2

This calculation is performed for each minute of valid TEOM data. To compute TEOM PM emission rate for a burn phase X or the entire IDC run, the 1-minute emission rates are averaged:

$$ER_{PM,L}^{TEOM} = Mean(ER_{PM,i}^{TEOM}) \quad \textit{(Eq. 6-130)}$$

Notice that only minutes with valid TEOM data are included in the averaging process.

Similar calculations are performed for unadjusted TEOM PM emission rate for comparison purposes.

B2.7.2.5 TEOM PM Emission Mass

The total mass of the PM emissions measured by TEOM is determined by the following formula for each burn phase L or the entire IDC test run:

$$m_{PM,L}^{TEOM} = ER_{PM,L}^{TEOM} \times \theta_L^{TEOM} \qquad \textit{(Eq. 6-131)}$$

The PM mass in this formula is calculated in grams and it can be converted to pounds by:

$$m_{PM,L}^{TEOM}(lb) = m_{PM,L}^{TEOM} \times 0.00220462 \qquad \textit{(Eq. 6-132)}$$

B2.7.2.6 TEOM PM Emission Factors

TEOM PM emissions are normalized based on the unit mass of the dry burned fuel ($\frac{g}{kg}$) or the unit of output energy ($\frac{g}{MJ}$ or $\frac{lb}{MMBtu}$). These emission factors are crucial metrics to evaluate and compare emissions from wood stoves.

The mass-based PM emission factor from TEOM measurements is calculated for each burn phase L and the entire IDC test run in grams per kilogram unit ($\frac{g}{kg}$) by dividing the total mass of the PM emissions, $m_{PM,X}^{TEOM}$ (section6.2.5), by the dry-basis mass of the burned fuel, $m_{burned,L}^{db}$ (section 2.3.6):

$$EF_{PM,L}^{TEOM} = \frac{m_{PM,L}^{TEOM}}{m_{burned,L}^{db}} \qquad \textit{(Eq. 6-133)}$$

PM emission factor should also be calculated per unit output energy of the stove. The total output energy, E_{out}, for the entire IDC run is estimated through the stove efficiency calculations, presented in section 4.4. Using the output energy, PM emissions per unit of output energy are calculated by:

$$EF_{PM}^{TEOM} = \frac{m_{PM,L}^{TEOM}}{E_{out,L}} \qquad \textit{(Eq. 6-134)}$$

where $EF_{PM,L}^{TEOM}$ is expressed in $\frac{g}{MJ}$ units. To convert it to the English system units ($\frac{lb}{MMBtu}$):

$$EF_{PM,L}^{TEOM}\left(\frac{lb}{MMBtu}\right) = EF_{PM,L}^{TEOM} \times \frac{0.00220462\times10^6}{947.817} \qquad \textit{(Eq. 6-135)}$$

B2.8 Data Quality Control and Validity

B2.8.1 Method 5G-X Data QC & Validation

This section provides a consolidated list of quality control (QC) measures and validation procedures required to ensure valid PM measurements using paired filter trains in dilution tunnel testing. These requirements are based on the Method 5G-X protocol and incorporate relevant elements from EPA Method 5G. The list includes sampling equipment checks, filter handling, flow control, proportionality, and sample analysis procedures that must be followed for each test run to be considered valid.

B2.8.1.1- Leak Checks

Post-test leak checks are mandatory. Leakage rate must be ≤ 4% of the average sampling rate. (5G-X Section 8.8)

B2.8.1.2- Flow Meter Calibration

Mass flow controllers must be calibrated annually with a NIST-traceable method and verified before and after each test set. Verification error must be ≤ 3%; if >5%, test results are void. *(5G-X Sections 10.2)*

B2.8.1.3- Analytical Balance Calibration

Multipoint calibration must be done before a test series using ASTM Class 1 weights. A daily audit is required with reproducibility within ±0.1 mg. *(5G-X Section 10.5; Method 5G Section 10.5)*

B2.8.1.4- Temperature Sensor and Barometer Calibration

Sensors must follow NIST Monograph 175; barometers must be NIST-traceable and calibrated semiannually. *(5G-X Sections 10.3, 10.4)*

B2.8.1.5- Field Blank Filters

Handling and measuring field blank filters are explained in Section 8.10.3 of NYSERDA Method 5G-X. Individual and average blank filter net mass values are reported for all blanks collected during a set of certification runs but are not subtracted from measured filter net mass. The average blank value must not be less than -0.10 mg for a set of certification tests to be valid.

Also, the limit of detection (LOD) is the greater of:

- 2 × range of all blanks
- 3 × standard deviation of blanks.

B2.8.1.6- Filter Handling and Weighing

Filters must be desiccated within 1 hour of the test and weighed after 20–24 hours of equilibration. Cold storage (1–4°C) is allowed for up to 7 days. (5G-X Section 8.12.1)

B2.8.1.7- Sampling Duration and Data Capture

At least 90% of the test minutes must be valid sampling time (excluding filter changes and door-open periods). (5G-X Section 8.10.4)

B2.8.1.8- Filter Temperature Control

Temperature between filters must remain ≤ 90°F as a 10-minute average. Up to 10 one-minute exceedances are allowed. (5G-X Section 8.10.1)

B2.8.1.9- Dilution Tunnel Flow and Mixing

Dilution tunnel flow rate is electronically recorded at 1-minute intervals and must be between 600 and 800 wet SCFM based on 10-minute average readings. Tunnel residence time at the flow used must be at least 1.6 seconds. No mixing baffles allowed. (5G-X Section 6.1.4)

B2.8.1.10- Sampling Proportionality

Calculation of the sampling ratio (SR) for Method 5G-X is explained in section 5.3. According to Section 12.7 of Method 5G-X, for a run to be valid:

- ≤10% of 10-min rolling average SR_i must fall outside 90–110% of SR_0.
- No 10-min rolling average SR_i must fall outside 80–120% of SR_0.

One-minute intervals while filters are changed and intervals while the appliance doors are open and 2 minutes after loading doors are closed may be discarded. (5G-X Section 12.7)

B2.8.1.11- Velocity Traverse and Discharge Coefficient

Velocity traverse must be performed before each test series. Discharge coefficient must be within 2% of the average for the series. (5G-X Section 8.5.1)

B2.8.1.12- Paired Train Agreement

Calculation of the relative precision of emission rates from filter trains a and b, ΔER_{PM}^{5GX}, is explained in Section 6.1.3 of this document.

According to Section 8.13 of Method 5G-X, the acceptable limit of ΔER_{PM}^{5GX} depends on the emission rate values:

- For $ER_{PM}^{5GX} > 1.0(\frac{g}{h})$ Acceptable $\Delta ER_{PM}^{5GX} = 15\%$
- For $0.5 \le ER_{PM}^{5GX} \le 1.0\ (\frac{g}{h})$ Acceptable $\Delta ER_{PM}^{5GX} = \frac{15\%}{\Delta ER_{PM}^{5GX}}$
- For $ER_{PM}^{5GX} < 0.5\ \left(\frac{g}{h}\right)$ Acceptable $\Delta ER_{PM}^{5GX} = 30\%$

B2.8.1.13- Sample Filter Changes

Filter changes are allowed during testing but must be documented. The sampling must resume within a short time and all filters accounted for. *(5G-X Section 8.10.4)*

B2.8.1.14- O-Ring Residue Handling

Mass of PM on O-rings must be recovered and added to the PM total if positive. *(5G-X Section 8.12.2.3)*

B2.8.1.15- Visual Inspection and Filter Documentation

Post-test, filters must be photographed and inspected for visible residue or contamination. *(5G-X Section 8.10.5)*

B2.8.1.16- Data Recording Requirements

Record 1-minute data for sample flow, filter temperature, tunnel Δp, and tunnel flow throughout the test. *(5G-X Section 8.10.2)*

B2.8.1.17- Tunnel Cleaning and Smoke Capture

Clean the tunnel before each certification series and confirm 100% smoke capture before testing. *(5G-X Sections 8.1 and 8.4)*

B2.8.1.18- Water in the Pitot Tube

For a run to be considered valid, no water should be detected in the pitot tube after each test run (5G-X 8.10.5).

B2.8.2 TEOM Data QC & Validation

This section summarizes the key quality control procedures and data validation criteria required when using the Thermo Scientific 1405-D TEOM instrument for measuring PM emissions under the NYSERDA TEOM SOP. These criteria ensure proper instrument setup, operation, filter management, and data integrity. For each test run to be considered valid, the following procedures and checks must be met and documented.

B2.8.2.1 Leak Checks

Leak test before and after each run must show ≤ 0.10 LPM (pre) and ≤ 0.15 LPM (post) for both channels. (Section 3)

B2.8.2.2 Flow Checks

Measured flows must be within ±2.0% of the setpoint pre-test and ±4.0% post-test using a NIST-traceable meter. (Section 3)

B2.8.2.3 K0 Calibration Verification

Verify mass transducer K0 values for both channels before and after a test series. The difference must be ≤ 2.0%. (Section 4)

B2.8.2.4 Filter Installation

Install new filters for both channels before each test run using proper procedures and tools. (Sections 2, 5)

B2.8.2.5 Filter Change Triggers

Change filters if loading reaches 115% or flow drops >5%. Continue the test run after proper replacement. (Section 2)

B2.8.2.6 Post-Change Confirmation

After filter change: frequency >200 Hz (1 min), mass difference ≤5 µg (5 min), and low noise. (Section 5)

B2.8.2.7 Clock Synchronization

TEOM clock must be within 5 seconds of lab clock; avoid reboots close to test start. (Section 2)

B2.8.2.8 Case Temperature Limit

Instrument case temperature must remain below 32.2°C (90°F) during operation. (Sections 2, 7)

B2.8.2.9 Record TEOM Settings

Save key settings (e.g., K0, flow setpoints) using RPComm before each test. (Section 2)

B2.8.2.10 Configuration Settings

Set data interval to 60 seconds; flows to 1.00 LPM; adjust mass constants and temperature settings. (Section 8)

B2.8.2.11 Filter Handling Protocols

Store and handle filters with care; use only approved tools; seat filters properly. (Section 5)

B2.8.2.12 1-Minute Data Validation

Minute data validation (step 2 in Figure 6-1) is performed manually on 1-min PM concentration data points. To facilitate and document this step NESCAUM has prepared a data processing and validation spreadsheet named "NYSERDA TEOM data template".

For each minute of the IDC test, the 1045-D Dichotomous TEOM records two raw PM concentration values: $C_{PM}^{TEOM(a),raw}$ ("PM-2.5 raw MC", the left channel) and $C_{PM}^{TEOM(b),raw}$ ("PM-Coarse raw MC", the right channel). The user should transfer the downloaded data from the csv file into the data processing and validation spreadsheet, following the instructions described in the spreadsheet (sheet 'Revisions'). According to the NYSERDA TEOM SOP document, raw PM concentration data points are considered valid only if all of the following criteria are met:

a) Flow reported by the instrument is within 5% of the flow setpoint (between 0.950 and 1.050 lpm for 1 lpm)
b) Operating mode (not system status): 3 or 4
c) Noise: 3-minute tunnel PM running average of (100 x noise / concentration) is < 0.20 µg
d) Case temperature: no higher than 32.2 °C (90 °F).
e) Concentration is not 0.00
f) Total Mass is not 0.00
g) Concentration is different from the preceding 1-minute interval.
h) For a valid minute of test data, at least one channel of Tunnel PM data must be valid.

Invalid data points must be manually removed as described in the data processing and validation spreadsheet instructions. Data that might be of questionable quality but pass all these validation criteria should be retained. If they are influential at the phase data level, they should be flagged for possible review. After identifying all invalid data points and removing them, for each 1-min interval there must be at least a valid concentration data. If both are invalid, then that minute's TEOM measurement is invalid. (Section 7)

B2.8.2.13 Phase Data Completeness

In addition to checking and validating data at 1-min intervals, TEOM data must be validated at the test run level (step 3 in Figure 6-1). With the validated 1-min TEOM data, the total number of minutes with valid (non-missing) measurements should be determined. For each 1-min interval there must be at least a valid concentration data. If both are invalid, then that minute's TEOM measurement is invalid. After each test run, we calculate the percentage of valid TEOM time, θ_L^{TEOM}, for each phase and the entire test run as explained in Section 6.2.2. Any burn phase and a test run with $85\% \leq \theta^{TEOM}$ is considered valid in terms of the TEOM valid data coverage. (Section 7)

B2.8.2.14 Channel Agreement

In addition to checking and validating data at 1-min intervals, TEOM data must be validated at the run level (step 3 in Figure 6-1). With the valid 1-min TEOM PM concentration values, we calculate the relative precision, $\Delta\bar{C}^{TEOM}_{PM,unadj.}$ (%) over the entire IDC test run as explained in Section 6.2.2. The value of $\Delta\bar{C}^{TEOM}_{PM,unadj.}$ must be no more than 7.5%. (Section 7)

B2.8.2.15 PM Emissions Calculation

Use only validated 1-minute PM data and wet tunnel flow for mass, emission rate, and emission factors calculations. (Section 7)

B2.8.3 Gas Measurement QC & Validation

The gas measurements include carbon monoxide (CO) and carbon dioxide (CO_2) and they are guided by EPA Methods 10 and 3A standards. Both standards refer to Method 7E for NOx, which has system calibration bias limits (5%).

A calibration correction should be calculated by the lab, after each post-IDC run calibration, as explained in Section 3.1. All calibrations must be within 5% of the calibration standard (cylinder) for CO and CO_2. In addition, there is a post-test drift calibration check that labs must perform and documents, and if this drift check fails to meet the required criteria (>3%), the entire test run will be considered invalid. To prevent the loss of emissions data, post-test drift calibration will be performed only after completing the entire test run, within 24 hours ± 2 hours of the pre-test calibration and must be less than 3%.

B2.8.4 IDC Protocol QC & Validation

Validating a test run to ensure compliance with the IDC test protocol requires adherence to numerous quality control procedures, equipment calibrations, environmental checks, data integrity practices, and test condition requirements. A full description of the test run validation requirements is provided in the "NYSERDA Integrated Duty Cycle Test Method for Certification of Wood-Fired Stoves" (IDC Test Protocol) document. The key criteria and checks are summarized below, with reference to the section numbers in the IDC Test Protocol document. Each IDC test run must satisfy all the following to be considered valid:

B2.8.4.1 Platform Scale Calibration

Multipoint calibration and audit using a NIST traceable weight before each test. (Section 9.2)

B2.8.4.2 Fuel Scale Calibration

Calibrated using the same protocol as the platform scale. (Section 9.6)

B2.8.4.3 Moisture Meter Validation

Checked before each day of use with a calibration block; annually calibrated to NIST standards. (Section 9.7)

B2.8.4.4 Barometer and Draft Gauge Calibration

Barometer calibrated semiannually or via nearby weather station; draft gauge per manufacturer's instructions. (Sections 9.3, 9.4)

B2.8.4.5 Temperature and Humidity Sensor Calibration

Calibrated using five points within the operating range, semiannually. (Sections 9.5, 9.9)

B2.8.4.6 TEOM Instrument Leak and Flow Checks
Conducted before and after every test run per NYSERDA TEOM SOP. (Section 12.3)

B2.8.4.7 Sampling System Leak Checks
Leak and flow checks required pre- and post-test for all PM sampling systems. (Section 12.1)

B2.8.4.8 Fuel Species, Supply, and Dimensions
Fuel must be untreated maple supplied by the lab, properly sized and shaped according to fuel calculator. (Sections 11.4.1–11.4.6)

B2.8.4.9 Fuel Moisture Content Validation
Each piece: 18–26% (dry basis); load average: 19–25%. (Section 11.4.2)

B2.8.4.10 Fuel Temperature Requirement
Test fuel must be between 55 and 87°F ±2°F. (Section 11.4.3)

B2.8.4.11 Test Facility Temperature
Must be between 55 and 87°F for each run. (Section 11.2.1)

B2.8.4.12 Ambient Air Velocity
Air velocity within 2 feet of the appliance must be <0.25 m/s (50 ft/min). (Section 11.2.5)

B2.8.4.13 Ambient Humidity and Barometric Pressure
Must be measured and recorded before and after each run. (Section 11.2.6)

B2.8.4.14 Dilution Tunnel Flow and Temperature Control
Must meet flow (>600 wet SCFM) and temperature (≤125°F max; ≤113°F 10-min avg) requirements with no more than two exceedances. (Section 10.1.3)

B2.8.4.15 No Condensation in Sampling Train
Presence of water anywhere in the sampling system invalidates the run. (Section 10.1.1)

B2.8.4.16 Dual Filter Trains Agreement
Filter trains 1 and 2 must meet Method 5G-X agreement criteria. (Section 10.2.3.1)

B2.8.4.17 TEOM Data Recording and Synchronization
1-minute TEOM data must be synchronized to master lab clock within 5 seconds. (Sections 8.25, 11.7.1)

B2.8.4.18 Stack Draft Measurements
Stack draft must be measured every minute during the test. (Sections 5.9, 10.4)

B2.8.4.19 CO and CO_2 Measurements
Must be measured every minute using modified EPA Methods 10 and 3A. (Sections 5.4, 5.5, 10.3.3)

B2.8.4.20 Phase Completion and Order
All four test phases (L1 through L4) must be completed in order without interruption. (Sections 5.7, 11.8)

B2.8.4.21Burn Rate Thresholds Maintained

Burn rate must exceed 0.1 lb every 40 minutes to avoid test termination. (Section 11.9.2.1)

B2.8.4.22 Fuel Adjustment Limitations

Phase-specific limits on number and timing of fuel adjustments (e.g., max 2 in L3 and L4 after first hour). (Sections 11.7.10.9, 11.7.11.4)

B2.8.4.23 Documentation and Video Recording

All active periods, fuel loading, air adjustments, and calibrations must be video recorded. (Section 11.7.8)

B2.8.4.24 Efficiency Calculations

Overall run efficiency must be based all run test data. Phase efficiencies should be calculated for L2, L3, and L4 data using calculations presented in Section 4. No external or supplemental data allowed. (Section 1.7.1)

B2.8.4.25 Data Rounding and Integrity

Raw decimal data must be retained throughout calculation stages. Only final PM emission values may be rounded. (Section 13.1)

B2.8.4.26 Reporting of All Runs

Data from valid, invalid, and incomplete runs must be fully reported. No exclusion is allowed. (Section 11.10.2)

B2.8.4.27 Calibration Record Retention

All calibration and audit records must be retained for 7 years and included in test reports. (Section 14.7.2)