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 shall have a thorough knowledge of at least the following EPA Tests

- Method 1- Sample and Velocity Traverses for Stationary Sources
- Method 2- Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)
- Method 3 – Gas Analysis for the Determination of Dry Molecular Weight
- Method 4 – Determination of Moisture Content in Stack Gases
- Method 5G – Determination of Particulate Matter from Wood Heaters (Dilution Tunnel Sampling Location)
- Method 10 - Carbon Monoxide - Instrumental Analyzer
- Method 25A - Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer

1. *Scope and Application*

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

1.2. Applicability. This method is applicable for the certification and auditing of wood space heaters, which burn cordwood fuel. Cordwood fuel is hand-fed. The test measures PM and CO emissions and calculates efficiency.

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

2. *Summary of Method*

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

2.2. PM emissions are measured by

2.2.1. Filter measurements. using dilution as specified in EPA Method 5G with the following modifications discussed in Section 8.

2.2.2. Real-time measurements. Thermo model 1405 TEOM using the Standard Operating Practices provides in Appendix 1, with dilution

3. Definitions

3.1. Catch - any mass from the sample probe system other than the PM on the front filter.

3.2. Certification or audit test - a series of at least three test runs conducted for certification or audit purposes that meets the specifications detailed in Section 8.

3.3. Chop – using a poker or another piece of wood to strike a piece of the fuel charge to break it into smaller pieces.

3.4. Coal-bed Stirring – prior to adding a new fuel charge, using a poker or piece of wood to stir or level the coal bed of the appliance for the sole purpose of ensuring ease of loading of the fuel charge. No special formations can be made, such as creating coal bed formations or pushing coals to one side or creating slopes with the coals.

3.5. Cordwood heater – an enclosed, wood-burning appliance capable of and intended for space heating or domestic water heating, as defined in the applicable regulation that combusts chunk fuels.

3.6. Firebox - the chamber in the wood heater in which the test fuel charge is placed and combusted.

3.7. Firebox Height - the vertical distance extending above the loading door, if fuel could reasonably occupy that space, but not more than 2 inches above the top (peak height) of the loading door, to the floor of the firebox (i.e., below a permanent grate) if the grate allows a 1-inch diameter piece of wood to pass through the grate, or, if not, to the top of the grate. Firebox height is not necessarily uniform but must account for variations caused by internal baffles, air channels, or other permanent obstructions.

3.8. Firebox length - the longest horizontal fire chamber dimension that is parallel to a wall of the chamber.

3.9. Fuel Adjustment –manipulations to the fuel charge to reflect typical owner practices that will allow the cordwood fuel to burn appropriately during the test period. A fuel adjustment does not include chopping the wood or stirring the coal bed. A fuel adjustment is minimal movement of a fuel charge piece or pieces that require no more than 30 seconds of time to complete.

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

3.11. High-fire Phase – period of the test when the unit has a small coal bed and the stoves air settings are fully open. Intended to replicate period when homeowners are trying to quickly heat an area, shortly after restarting the appliance.

3.12. Kindling pieces – small pieces of wood less than 1" in diameter. No bark or moisture requirements for these pieces. Fuel length must be at least 50% of the fuel charge length and shall represent weights that would enable 8 to 10 pieces equal one pound.

3.13. Large fuel pieces – pieces that are larger for the appliance as defined by the fuel load calculator.

3.14. Maintenance-fire phase– period of the test when the unit has a coal bed and refractory has gained temperature, and the fire can be maintained with a medium-sized coal bed. Intended to replicate the period when homeowners are trying to maintain heat in an area.

3.15. Overnight Burn Phase– period of the test when the unit has a large coal bed, stove is fully loaded, and the appliance air settings are at their lowest flow settings. Intended to replicate the period when homeowners are trying to maintain heat over a long period of time, such as overnight or while away for significant periods of time.

3.16. 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.

3.17. Small fuel pieces - pieces that are small for the appliance as defined by the fuel load calculator.

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

3.19. Start-up – period of the test when the unit has kindling and start-up fuel. Stove has not burned any fuel for a period of at least 48 hours (stove does not need to be on the test stand before this period) for the first test run and at least 8 hours for the 2nd and 3rd test runs. No coal bed, sand, ash exists in the appliance. Stove air settings are fully open, unless otherwise specified in the manufacturers User Guide.

3.20. Test – means the data for all test runs conducted on the wood heater.

3.21. Test facility - the area in which the wood heater is installed, operated, and sampled for emissions.

3.22. Test fuel charge - the collection of test fuel pieces placed in the wood heater during the four phases of the test run. Each test fuel load shall have at least 75% of the individual pieces with at least 80% bark on one side of the fuel piece.

3.23. Test fuel load – the group of test fuel pieces that are loaded, as specified, throughout the test run. Test fuel loading means the arrangement of the test fuel charge

3.24. Test fuel loading density - the calculation that determines the weight of the as-fired test fuel load. The calculation is based on a per unit volume of usable firebox.

3.25. Test run - an individual emission test that encompasses the time required to run the device in the four operational phases and consume 90% of the mass of the four test fuel charges encompassed within the test.

3.26. Usable firebox volume - the volume of the firebox determined using its height, length, and width as defined in this section.

3.27. Width - the shortest horizontal fire chamber dimension that is parallel to a wall of the chamber.

3.28. 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*

[Reserved]

5. *Safety*

5.1. 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.

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

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

6.2. Balance (optional). Balance capable of weighing the test fuel charge to within 0.02 kg (0.05 lb.).

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

6.4. Dilution Tunnel. The dilution tunnel apparatus is shown in Figure 5G–2 and consists of the following components:

6.4.1. Hood. Constructed of steel with a minimum diameter of 0.3 m (1 ft) on the large end and a standard 0.15 to 0.3 m (0.5 to 1 ft) coupling capable of connecting to standard 0.15 to 0.3 m (0.5 to 1 ft) stove pipe on the small end. Method 5G 8/3/2017.

6.4.2. 90° Elbows. Steel 90° elbows, 0.15 to 0.3 m (0.5 to 1 ft) in diameter for connecting mixing duct, straight duct, and optional damper assembly. There shall be at least two 90° elbows upstream of the sampling section (see Figure 5G–2).

6.4.3. Straight Duct. Steel, 0.15 to 0.3 m (0.5 to 1 ft) in diameter to provide the ducting for the dilution apparatus upstream of the sampling section. Steel duct, 0.15 m (0.5 ft) in diameter, shall be used for the sampling section. In the sampling section, at least 1.2 m (4 ft) downstream of the elbow, shall be two holes (velocity traverse ports) at 90° to each other of sufficient size to allow entry of the pitot for traverse measurements. At least 1.2 m (4 ft) downstream of the velocity traverse ports, shall be one hole (sampling port) of sufficient size to allow entry of the sampling probe. Ducts of larger diameter may be used for the sampling section, provided the specifications for minimum gas velocity and the dilution rate range shown in Section 8 are maintained. The length of the duct from the hood inlet to the sampling ports shall not exceed 9.1 m (30 ft).

6.4.4. Mixing Baffles. Steel semicircles (two) attached at 90° to the duct axis on opposite sides of the duct midway between the two elbows upstream of the sampling section. The space between the baffles shall be about 0.3 m (1 ft). 6.1.4.5 Blower. Squirrel cage or another fan capable of extracting gas from the dilution tunnel of sufficient flow to maintain the velocity and dilution rate specifications in Section 8 and exhausting the gas to the atmosphere.

6.5. Draft Gauge. Electromanometer or other devices for the determination of flue draft or static pressure readable to within 0.50 Pa (0.002 in. H2O)

6.6. Humidity Gauge. Psychrometer or hygrometer for measuring room humidity.

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

6.8. Moisture Meter. Calibrated electrical resistance meter for measuring test fuel moisture to within 1 percent moisture content.

6.9. Platform Scale and Monitor. For monitoring of fuel load weight change. The scale shall be capable of measuring weight to within 0.0045 kg (0.01 lb.).

6.10. Sample Analysis. The following items are required for sample analysis: glass weighing dishes, desiccator, analytical balance, beakers (250-ml or smaller), hygrometer, and temperature sensor. Same as Method 5, Sections 6.3.1 through 6.3.3 and 6.3.5 through 6.3.7, respectively.

6.11. Sample Recovery. The following items are required for sample recovery: probe brushes, wash bottles, sample storage containers, petri dishes, and funnel. Same as Method 5, Sections 6.2.1 through 6.2.4, and 6.2.8, respectively.

6.12. Sampling Train. The sampling train configuration is shown in Figure 5G–1 and consists of the following components:

6.12.1. Probe. Stainless steel (e.g., 316 or grade more corrosion resistant) or glass about 9.5 mm (3/8in.) I.D., 0.6 m (24 in.) in length. If made of stainless steel, the probe shall be constructed from seamless tubing.

6.12.2. Pitot Tube. Type S, as described in Section 6.1 of Method 2. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Method 2, Section 10. Alternatively, a standard pitot may be used as described in Method 2, Section 6.1.2.

6.12.3. Differential Pressure Gauge. Inclined manometer or equivalent device, as described in Method 2, Section 6.2. One manometer shall be used for velocity head (Δp) readings and another (optional) for orifice differential pressure readings (ΔH).

6.12.4. Filter Holders. Two each made of borosilicate glass, stainless steel, or Teflon, with a glass frit or stainless steel filter support and a silicone rubber, Teflon, or Viton gasket. The holder design shall provide a positive seal against leakage from the outside or around the filters. The filter holders shall be placed in series with the backup filter holder located 25 to 100 mm (1 to 4 in.) downstream from the primary filter holder. The filter holder shall be capable of holding a filter with a 47 mm diameter.

6.12.5. Filter Temperature Monitoring System. A temperature sensor capable of measuring temperature to within ±3°C (±5°F). The sensor shall be installed at the exit side of the front filter holder so that the sensing tip of the temperature sensor is in direct contact with the sample gas or in a thermowell as shown in Figure 5G–1. The temperature sensor shall comply with the calibration specifications in Method 2, Section 10.3. Alternatively, the sensing tip of the temperature sensor may be installed at the inlet side of the front filter holder.

6.12.6. Dryer. Any system capable of removing water from the sample gas to less than 1.5 percent moisture (volume percent) prior to the metering system. The system shall include a temperature sensor for demonstrating that sample gas temperature exiting the dryer is less than 20°C (68°F).

6.12.7. Metering System. Same as Method 5, Section 6.1.1.9. 6.1.2 Barometer. Same as Method 5, Section 6.1.2. 6.1.3.

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

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

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

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

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

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

6.15. Wood Heater Flue.

6.15.1. Steel flue pipe extending to 2.6 ±0.15 m (8.5 ±0.5 ft) above the top of the platform scale, and above this level, insulated solid pack type chimney extending to 4.6 ±0.3 m (15 ±1 ft) above the platform scale, and of the size specified by the wood heater manufacturer. This applies to both freestanding and inserts type wood heaters.

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

6.16. Wood Heater Temperature Monitors. Seven, each capable of measuring temperature with standard Type J or K thermocouple accuracy of +/- 0.75% of expected absolute temperatures.

7. *Reagents and Standards*

7.1. Sample Collection. The following reagents are required for sample collection:

7.1.1. Teflon coated filters such as Pallflex Emfab (TX40) with a maximum diameter of 47 mm, without organic binder, exhibiting at least 99.95 percent efficiency.

7.1.2. Stopcock Grease. Same as Method 5, Section 7.1.5 Sample Recovery. Acetone-reagent grade,

7.1.3. same as Method 5, in Section 7.2.

7.1.4. Sample Analysis. Two reagents are required for the sample analysis:

7.1.5. Acetone. Same as Method 5, in Section 7.2.

7.1.6. Desiccant. Anhydrous calcium sulfate, calcium chloride, or silica gel, indicating type.

7.2. Test Fuel. The test fuel shall conform to the following requirements:

7.2.1. Fuel Species. Untreated, air-dried, cordwood fuel.

7.2.1.1. Allowable species: maple (big leaf, red, silver).

7.2.1.2. Kiln-dried fuel is not permitted.

7.2.1.3. Fuel shall be free of decay, fungus, or other contaminants.

7.2.2. Fuel Moisture.

7.2.2.1. The test fuel shall have a moisture content range between 16 to 20 percent on a wet basis (19 to 25 percent dry basis).

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

7.2.2.3. Use of kiln-dried wood is not allowed

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

7.2.2.5. Fuel moisture shall be measured within 24 hours of using the fuel for the test and shall be stored in a humidity-controlled environment prior to testing.

7.2.3. Fuel Temperature. The test fuel shall be at the test facility temperature of 18 to 32°C (50 to 90°F).

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

7.2.4.1. Fuel length: The length of the piece will be determined by the fuel load calculator. Measurements shall be taken, and the length of the test fuel will be determined by entering the firebox dimensions, which calculates the length for all the fuel pieces into a generally available commercial size (14, 16, 18, 20 or

22 inches in length). Piece length shall follow the loading direction specified for us in the owner's manual. Sold stoves with an east/west configuration may not test with fuel in a north/south configuration and vice versa.

7.2.4.2. Fuel Piece Weight for each phase of the protocol shall be determined by the fuel load calculator.

7.2.4.2.1. Kindling - small pieces of wood less than 1" in diameter. No bark requirements for these pieces. No species requirements. No moisture requirements. Length of kindling shall be 50% to 100% of the fuel length specified by the fuel load calculator.

7.2.4.2.2. Starter fuel: pieces of cordwood shall be used during the startup phase. Individual piece weight for starter fuel shall be determined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in shape. Use of square pieces shall be avoided (see Figure 1). Pieces that have squared ends shall be shaved to represent the typical triangle nature of wood (see Figure 2).

7.2.4.2.3. Small fuel pieces: smaller pieces of cordwood by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in shape. Use of square pieces shall be avoided (see figure 1). Pieces that have squared ends shall be shaved to represent the typical triangle nature of wood (see Figure 2).

7.2.4.2.4. Large fuel pieces: larger pieces of cordwood, by weight and pre-defined length, as defined by the fuel load calculator. Each piece shall be triangular, irregular, or circular in shape. Use of square pieces shall be avoided (see figure 1). Pieces that have squared ends shall be shaved to represent the typical triangle nature of wood (see Figure 2).

Figure 1. Schematic of unacceptable shape profiles

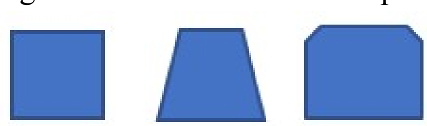


Figure 2. Schematics of acceptable shape profiles

8. Sample Collection, Preservation, Storage, and Transport

8.1. Test Run Requirements.

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

8.1.1.1. Directions must be illustrated by text and pictures

8.1.1.1.1. Font size – minimum font size is 12.

8.1.1.1.2. Use of columns allowed

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

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

8.1.1.1.5. Must fit on a single side of an 8 x11.5-inch sheet of paper

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

8.1.1.2. User Guide elements – The User Guide shall not include exact specifications for fuel piece size, fuel placement, fuel-spacing nor shall it specify the number of pieces per row of the fuel charge. For example, the User Guide shall specify what direction the fuel should be laid but not measurements required between fuel pieces. The User Guide shall include information on the following items.

8.1.1.2.1. Stove preparation – what must be done to the stove prior to starting a fire.

8.1.1.2.2. Fuel properties – what types of fuel and fuel moisture requirements are allowed for use in the appliance. The fuel properties detailed in the User

Guide are for homeowner use, for certification testing, fuel requirements shall follow the protocols detailed in this method.

8.1.1.2.3. Start-up procedures – general guidelines for properly starting a fire in the stove. For example, instructions can specify using a top-down or teepee style for building the fire, but the User Guide cannot specify that a specific number of pieces with a specific measurement between pieces.

8.1.1.2.4. Reloading procedures – guidelines for properly reloading fuel once a fire has been started in the stove. For example, User Guide can direct pattern of piece placement, for example add pieces in a specific direction. The User Guide cannot specify specific piece size, spacing size between pieces.

8.2. Test run requirements – the following are the pre-testing stove use requirements for each test run.

8.2.1. Run 1 – stove must be at lab temperature and wait a minimum of 72 hours without combustion before starting Run 1.

8.2.2. Run 2 – shall at a minimum 8 hours from the conclusion of Run 1 before commencing Run 2. Stove coals and ash can remain in the stove until 1 hour before conducting Run 2. All coals and ash must be removed before commencing Run 2.

8.2.3. Run 3 – shall at a minimum 8 hours from the conclusion of Run 2 before commencing Run 3. Stove coals and ash can remain in the stove until 1 hour before conducting Run 3. All coals and ash must be removed before commencing Run 3.

8.2.4. Burn Phase Categories. Each emission test run shall include all phases of the operational and fueling protocol: start-up, coal bed development phase, maintenance fire phase, overnight burn simulation phase. If a wood heater cannot be operated at the settings specified in the test procedure, the test run is a failed run. If after three attempts to run the device according to the protocol, the unit cannot maintain a fire, the unit has failed the test. The unit cannot be retested unless appliance design parameters are modified to improve performance, as indicated on design drawings and appliance specifications.

8.3. Wood Heater Aging. A wood heater of any type shall be aged before initiating a certification test. The aging procedure shall be conducted and documented by a testing laboratory. Operate the appliance using fuel cordwood with moisture content between 15 and 25 percent on a wet basis. Operate the wood heater at a variety of burn phases. The test report shall detail the amount of fuel burned, fuel parameters (species, moisture content, load weights), and burn rates.

8.3.1. If an appliance uses a catalytic combustor, it must be engaged according to the manufacturer's instructions and operate for at least 40 hours during the break-in period. Report hourly catalyst exit temperature data and the hours of operation.

8.3.2. Record air settings used and note the time spent in each air setting phase.

8.4. Pretest Recordkeeping.

8.4.1. Record data and detailed information on all testing or burning completed on the appliance, including all pre-test burns conducted at the testing facility or by the manufacturer at minimum10-minute intervals. Pre-burns conducted at the manufacturer shall conform to the same requirements as the test facility. This information shall include the amount of wood burned, air settings, burn times and dates, stove and stack temperature data.

8.4.2. Test fuel loads - the test fuel charge weights for the start-up, high fire, maintenance fire, and low fire charges. For each charge record the number of pieces in the charge, moisture content of each piece and weight of each piece. Obtain photo documentation and description of the wood heater, catalysts (if applicable), and fuel charges.

8.5. Wood Heater Installation. Assemble the wood heater appliance and parts in conformance with the manufacturer's written installation instructions. Place the wood heater centrally on the platform scale and connect the wood heater to the flue. Clean the flue with an appropriately sized, wire chimney brush before each initiating Run 1 of the certification test. Test documentation should include the date and time of flue cleaning.

8.6. Wood Heater Temperature Monitors.

8.6.1. 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 in.) downstream at the centroid of the catalyst face area. Record these locations.

8.6.2. Locate wood heater surface temperature monitors at five locations on the wood heater firebox exterior surface. Position the temperature monitors centrally on the top surface, on two sidewall surfaces, and on the bottom and back surfaces. Position the monitor sensing tip on the firebox exterior surface inside of any heat shield, air circulation walls, or other wall or shield separated from the firebox exterior surface. Surface temperature locations for unusual design shapes (e.g., spherical, etc.) shall be positioned so that there are four surface temperature monitors in both the vertical and horizontal planes passing at right angles through the centroid of the firebox, not including the fuel loading door (total of five temperature monitors).

8.7. Modifications to EPA Method 5G requirements.

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

8.7.2. Dilution tunnel temperature and relative humidity shall be measured and logged near the sample probe to calculate dewpoint. Filter temperature shall be measured and logged. Temperature shall use a measurement method with an accuracy of 0.5 degrees Celsius (C).

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

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

8.7.3.2. Tunnel temperature shall not exceed 100 deg. F (37.8 C)

8.7.3.3. Tunnel relative humidity shall not exceed 90%.

8.7.3.4. Tunnel dew point temperature shall be at least 2 deg. C less than filter temperature.

8.7.3.5. If any parameter is exceeded, the test report should explicitly note the results of the sampling train liquid water inspection.

8.7.4. Proportionality shall be limited to ± 5%, using, at a minimum, 10-minute data.

8.8. Test Facility Conditions.

8.8.1. 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 1 to 2 m (3 to 6 ft) from the front of the wood heater in the 90° sector in front of the wood heater.

Use an anemometer to measure the air velocity. Measure and record the room air velocity before the pretest ignition period (Section 8.7) and once immediately following the test run completion.

8.8.2. Measure and record the test facility's ambient relative humidity, barometric pressure, and temperature before and after each test run.

Measure and record the flue draft or static pressure in the flue at a location no greater than 0.3 m (1ft) above the flue connector at the wood heater exhaust during the test run at the recording intervals

8.9. Wood Heater Firebox Volume.

8.9.1. Determine the firebox volume using the definitions for height, width, and length in Section 3. Volume adjustments due to the presence of firebrick and other permanent fixtures may be necessary. Adjust width and length dimensions to extend to the metal wall of the wood heater above the firebrick or permanent obstruction if the firebrick or obstruction extending the length of the side(s) or back wall extends less than one-third of the usable firebox height. Use the width or length dimensions inside the firebrick if the firebrick extends more than one-third of the usable firebox height. If a log retainer or grate is a permanent fixture and the manufacturer recommends that no fuel be placed outside the retainer, the area outside of the retainer is excluded from the firebox volume calculations

8.9.2. In general, exclude the area above the ash lip if that area is less than 10 percent of the usable firebox volume. Otherwise, consider consumer loading practices. For instance, if fuel is to be loaded front-to-back, an ash lip may be considered usable firebox volume.

8.9.3. Include areas adjacent to and above a baffle (up to two inches above the fuel loading opening) if four inches or more horizontal space exist between the edge of the baffle and a vertical obstruction (e.g., sidewalls or air channels).

8.10. Test Fuel Charge.

8.10.1. Prepare the test fuel pieces in accordance with the specifications in the fuel load calculator.

8.10.2. Determine the test fuel moisture content with a calibrated electrical resistance meter or other equivalent performance meters, as defined in Section 6.6. If necessary, convert fuel moisture content values from dry basis (%Md) to a wet basis (%Mw). Determine fuel moisture for each fuel piece by averaging four moisture meter readings, one from each of three sides, measured parallel to the wood grain. Moisture readings will include two core measurements and two shell measurements. One of the core measurements and one of the shell measurements shall be made at the center of the length of each piece. The second core measurement and the second shell measurement shall be made approximately one inch from one end of each piece. Either end may be selected for this measurement. The shell measurements shall be made with a penetration of this moisture meter insulated electrodes of ¼ inch. The core measurements shall be mode with a penetration of a moisture meter insulated electrodes to the center of the piece or a distance of 1.125 inch, whichever is less. For core measurements, a pilot hole is drilled to a distance of not greater than1/4 inch less than the target penetration distance. Each individual moisture content reading shall be in the range of 10-35% MC on a dry basis — average all the readings for all the fuel pieces in the test fuel charge.

8.10.3. Determine the fuel temperature by measuring the temperature of the room where the wood has been stored for at least 24 hours prior to the moisture determination.

8.11. Sampling Equipment.

8.11.1. Prepare the sampling equipment as defined by EPA Method 5G and the TEOM SOP contained in Appendix A.

8.11.2. Sample Flow Corrections for Water Vapor: Corrections shall use the average of actual tunnel dew point measurements during a sample run, use of the assumed dew point value is prohibited.

8.12. Instructions

8.12.1. Wood Heater Operation and Adjustments. Set the air inlet supply controls as designated in the operational protocol in Section 8.11. For the purposes of this method, coalbed raking is the use of a metal tool (poker) to stir coals, break burning fuel into smaller pieces, dislodge fuel pieces from positions of poor combustion, and check for the condition of uniform charcoalization for the low-fire phase. 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. Record fuel weight data and wood heater temperature measurements at 1-minute intervals.

8.12.2. The weight of fuel remaining at the end of the test run is determined as the difference between the weight of the wood heater with the remaining coals and fuel and the weight after loading the fuel charge. The starting weight is the tare weight of the cleaned, dry wood heater with or without dry ash or sand added consistent with the manufacturer's instructions and the owner's manual. The tare weight of the wood heater must be determined with the wood heater (and ash, if added) in a dry condition.

8.13. Test Run. A complete test run requires completion of all four burn phases and loads, as described below. For any appliance that will not accommodate the loading arrangement specified in this test method, the test facility personnel shall contact the Agency Administrator to obtain written approval for an alternative loading arrangement:

8.13.1. Start-up Phase

8.13.1.1. Stove temperature: internal and external stove temperature must not be greater than 75F for Run 1. No stove temperature requirements for Run 2 and 3. Temperature measurements for the external and internal temperatures shall be taken 15 minutes before starting the test and shall be reported in the test report.

8.13.1.2. Record the weight of the stove prior to initiating the test and record the weight of the start-up fuel charge prior to loading.

8.13.1.3. Fuel type – during the start-up phase newspaper (optional up to six full sheets traditional newspaper size), kindling and starter fuel pieces are used.

8.13.1.4. Loading Density

8.13.1.4.1. Kindling loading density: 1 lb. per cubic foot for dry kindling maximum. The fuel load calculator determines the maximum amount of kindling that can be used.

8.13.1.4.2. Starter Fuel loading density: 3 lb. per cubic foot, +/- 5%. The fuel load calculator will determine the minimum piece weight that can be used as starter fuel.

8.13.1.5. Loading structure: The loading structure will be guided by the User Guide, if no User Guide is supplied, a structure using a bottom-up structure will be used.

8.13.1.6. Operational Parameters:

8.13.1.6.1. All kindling and newspaper must be in the firebox for light off. Starter fuel may be added at any interval during the startup phase, including from the cold start.

8.13.1.6.1.1. Structure of load is determined by manufacturers' instructions

8.13.1.6.1.2. Air settings are defined by the User Guide if no instructions are provided air settings will be fully open.

8.13.1.6.2. The door can be open for a maximum of five (5) minutes during the start-up phase. Door settings shall be specified in the User Guide. Certification testing shall not deviate from door conditions described in the User Guide.

8.13.1.7. Fuel Adjustments: unlimited poking and stirring during the cold start phase. The door can only be open for 30 seconds for fuel adjustments.

8.13.1.8. End of Phase – the end of the start-up phase is defined by the coal bed weight obtained using the fuel load calculator.

8.13.2. *High-fire Phase* – the high fire phase commences immediately after the start-up phase ends.

8.13.2.1. Stove temperature: no stove temperature requirements.

8.13.2.2. Record the weight of the stove prior to loading the high-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the high-fire fuel charge.

8.13.2.3. Fuel type – during the high-fire phase, small cordwood pieces by weight, as defined by the fuel load calculator.

8.13.2.4. Loading structure: fuel will be loaded in a random pattern unless otherwise specified by the User Guide and conforms to the requirements of Section 8.1.1.2.4. A picture or video of the loading pattern shall be included in the test report.

8.13.2.5. High-fire 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.

8.13.2.6. Operational Parameters: Open the door upon completion of the start-up phase and load the high fire fuel charge within the first minute (60 seconds) of the high-fire phase. Once the fuel has been loaded, the appliance doors are closed immediately, and air settings are fully open. When 50% of the high-fire phase fuel load has been consumed, air settings shall be changed to the lowest air settings capable of the appliance.

8.13.2.7. Fuel Adjustments:

8.13.2.7.1. One voluntary fuel adjustment is allowed during the high-fire phase. The door can only be open for 30 seconds for fuel adjustments.

8.13.2.7.2. Additional fuel adjustments shall be made if there is a five-minute period without a weight change at any point during the high-fire phase. A fuel adjustment must be made until the appliance has a yellow flame fire.

8.13.2.8. End of Phase – the end of the high-fire phase is as when the scale indicates that 90% of the total high-fire fuel charge has been consumed.

8.13.3. *Maintenance-fire Phase* – the maintenance-fire phase commences immediately after the high-fire phase ends.

8.13.3.1. Stove temperature: no stove temperature requirements.

8.13.3.2. Record the weight of the stove prior to loading the maintenance-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the maintenance-fire fuel charge.

8.13.3.3. Fuel type – during the Maintenance-fire 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.

8.13.3.4. Loading structure: fuel will be loaded in a random pattern unless otherwise specified by the User Guide and conforms to the requirements of Section 8.1.1.2.4. A picture or video of the loading pattern shall be included in the test report. A picture or video of the loading pattern shall be included in the test report.

8.13.3.5. Maintenance-fire 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.

8.13.3.6. Operational Parameters: Open door upon completion of the high-fire phase and load the maintenance-fire fuel charge. The maintenance fuel load must be loaded into the stove within 60 seconds of the start of this phase. Close door immediately. Air settings remain at the lowest-air setting.

8.13.3.7. Fuel Adjustments: If there is no yellow flame or five-minute period without weight change at any point during the maintenance-fire phase, a mandatory fuel adjustment must be made to obtain a yellow flame. The door can only be open for 30 seconds for fuel adjustments.

8.13.3.8. End of Phase – the end of the maintenance-fire phase is when the scale indicates that 90% of the total maintenance-fire fuel charge has been consumed.

8.13.4. *Overnight-fire Phase* – the overnight-fire phase commences immediately after the maintenance-fire ends.

8.13.4.1. Stove temperature: no stove temperature requirements.

8.13.4.2. Record the weight of the stove prior to loading the overnight-fire fuel charge, the load of the fuel charge prior to loading, and the scale weight after loading the overnight-fire fuel charge.

8.13.4.3. Fuel type – during the overnight-fire phase, a mix of small and large cordwood pieces are used. At least 50% of the fuel charge load, by number of pieces, must be large pieces.

8.13.4.4. Loading structure: fuel will be loaded in one direction and in such a manner to load the greatest amount of fuel possible without force and to maintain at least one inch from the top of the stove or tubes and is in conformance with the User Guide and section 8.1.1.2.4. A picture or video of the loading pattern shall be included in the test report.

8.13.4.5. Overnight-fire loading density: The fuel load calculator will specify a load volume of 14 lb/ft^3. This load may include pieces that will not fit into the appliance. Fuel will be loaded to the top of the appliance with as many pieces as possible that can be put in the appliance without force. The total weight of the fuel load will be calculated after loading is completed. The test lab shall weigh the pieces not loaded and subtract from the earlier weight, entering that data into the fuel load calculator. The target and actual fuel loading density shall be recorded and reported. Overnight-fire phase load density must be a minimum of 10 lb./ft^3.

8.13.4.6. Operational Parameters: Open door upon completion of the maintenance-fire phase. Load the overnight-fire fuel charge within one minute (120 seconds) of the start of the overnight-fire phase. The door may remain open for up to five minutes from the beginning of the phase period, as described in the User Guide. Air settings may be placed at any air setting within the first ten minutes of the phase. Unlimited fuel adjustments are allowed within the first five minutes of the test. After ten minutes, air settings must be at the lowest position.

8.13.4.7. Fuel Adjustments: If there is no yellow flame or scale weight change for a period of 5 minutes at any point during the overnight-fire phase, a fuel adjustment shall be completed.

8.13.4.8. End of Phase – the end of the overnight-fire phase is when the scale indicates that 90% of the total overnight-fire phase fuel charge has been consumed.

8.13.5. Data Recording.

8.13.5.1. Three Method5G trains will be used for this testing.

8.13.5.1.1. Proportionality shall be limited to ± 5%, using 10-minute data.

8.13.5.1.2. Start-up Measurement – A measurement of the start-up phase will be reported using one Method 5G train. This measurement will commence at the beginning of the start-up phase and ends at the end of the start-up phase.

8.13.5.1.3. Integrated load measurement. Two, dual Method 5G trains will measure the entire run from the beginning of the start-up phase through the end of the overnight burn will be reported.

8.13.5.2. TEOM data will be collected at 10-second intervals and averaged up to 1-minute intervals for reporting. TEOM operation shall follow the procedures listed in Appendix A and operated following section 6 protocols in that Appendix.

8.13.5.3. Data shall be recorded on an excel spreadsheet following the minimum data reporting requirements.

8.13.6. Test Fuel Charge Adjustments: are allowed only as specified in section 8.11.

8.13.7. Auxiliary Wood Heater Equipment Operation. If heat exchange blowers are sold with the wood heater, two sets of test runs shall be completed, one without the blower and the second with the blowers operated during the test run following the manufacturer's written instructions. If no manufacturer's written instructions are available, operate the heat exchange blower in the “high” position. (Automatically operated blowers shall be operated as designed.) Shaker grates, by-pass controls, or other auxiliary equipment may be adjusted only one time during the test run following the manufacturer's written instructions. Record all adjustments on a wood heater operational written record.

8.13.8. Test Run Completion. Test runs ends when all four phases of the test run have been completed, and 90% of the overnight fire test fuel charge has been consumed.

8.13.9. Consecutive Test Runs. Consecutive test runs may be conducted, provided that the requirements of 8.1.2. are met.

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

8.13.10.1. Two filter measurements shall be reported.

8.13.10.1.1. Start-up. Emissions from match light until the end of the start-up phase shall be collected and reported as a separate element using one Method 5G train and compared with TEOM start-up phase emissions.

8.13.10.1.2. Integrated Result. The start-up, high, maintenance, and overnight fire phase will be integrated into a single emission results.

8.13.10.2. TEOM data shall be reported.

8.13.10.2.1. Emissions from each of the 4 phases of the test shall be reported as individual results in both grams per hour and grams per kilogram.

8.13.10.2.2. Emissions from the entire test run.

8.13.10.3. Test Series completion. A complete test series is defined as the successful completion of three full test runs as specified in 8.1.2.

8.13.10.4. Additional Test Runs. The testing laboratory may conduct more than three test runs. If more than three test runs are conducted, the results from all valid test runs shall be used in calculating the average emission rate. The measurement data and results of all test runs shall be reported regardless of which values are used in calculating the emission rate. No test run data can be eliminated unless it is conducted in a manner that invalidates the result.

9. *Quality Control* – Same as section 9.0 of Method 5G.

10. *Calibration and Standardizations* – Same as Section 10.0 of Method 5G with the addition of the following:

10.1. Platform Scale. Perform a multi-point 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 0.0045 kg (0.01 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.

10.2. Balance (optional). Calibrate as described in Section 10.1.

10.3. Temperature Monitor. Calibrate as in Method 2, Section 4.3, before the first certification test and semiannually thereafter.

10.4. Moisture Meter. Calibrate as per the manufacturer's instructions before each certification test.

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

10.6. Barometer. Calibrate against a mercury barometer before the first certification test and semiannually thereafter.

10.7. Draft Gauge. Calibrate as per the manufacturer's instructions; a liquid manometer does not require calibration.

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

11. Analytical Procedures – Same as Section 11.0 of Method 5G

11.1.1. Weigh room conditions – the following conditions shall be met:

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

11.1.1.2. Temperature range of 68 to 78 deg. F.

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

11.1.2. Filter equilibration / conditioning post sample collection: Use of desiccation is not allowed. Equilibrate filters at a relative humidity between 30 and 40% for at least 24 hours. A saturated salt solution of magnesium chloride (33% RH) can be used.

11.1.3. Report the following filter measurements:

11.1.3.1. Day zero – initial filter measurement immediately after completing testing.

11.1.3.2. Day one – filter measurement 24 hours from completion of testing, +/- 60 minutes.

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

11.1.4. Blanks: test reports shall measure and report data on blanks as follows:

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

11.1.4.2. Room blank collected during every test run. The blank shall be placed within 2 feet of the intake for the dilution air and shall be placed at a minimum of 10 feet away from any combustion activities.

11.1.4.3.).

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

12. Data Analysis, Calculations and Reporting Requirements.

AER = Ei/∑N
BT = time of 90% of overnight load consumed – time of overnight loading
Ei = Emission rate for test run, g/hr (lb/hr), lb/MMBtu
$\%M_d$ = Fuel moisture content, dry basis, percent.
$\%M_w$ = Average moisture in test fuel charge, wet basis, percent.
N = Total number of test runs.
W_{wd} = Total mass of wood burned during the test run, kg (lb).
Wet Basis Fuel Moisture Content.
$\%M_w = 100(\%M_d)/100+\%M_d$
Average Emission Rate (AER).

12.1. Average Wood Heater Surface Temperatures. Calculate the average of the wood heater surface temperatures for the start of the test run (Section 8.11.1) and for the test run completion (Section 8.11.4). Average wood heater surface temperatures must confirm to starting temperature requirements (Section 8.11.1).

12.2. Burn Time – standard reporting of burn times shall be calculated based on the time the overnight load is put into the appliance and the time it takes to combust 90% of that fuel load.

12.3. Efficiency calculation.

Ultimate Analysis of dry fuel (% by weight)
Carbon – CA
Hydrogen – HY
Oxygen – OX
Moisture Content – mass of water per mass of dry fuel – Mcdb
Ambient Humidity Ratio – mass of water per unit mass of dry air – ω
Flue gas temperature (F) – Ts
Room temperature (F)-Tr
CO in the dry flue gas (ppm) – PPMco
CO2 in the dry flue gas (%) – PCTCO2
Higher heating value of the dry fuel (lb/MMBtu) – HHV

<u>Combustion Balance Equation:</u>

$$C_xH_yO_z + (1+\alpha)\bullet\gamma(O_2 + 3.76N_2) + \left[\omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32+3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right]H_2O$$

$$\rightarrow (x-\beta)\,CO_2 + \beta CO + (\alpha\bullet\gamma + \frac{\beta}{2})\,O_2 + (1+\alpha)\bullet\gamma\bullet 3.76\,N_2 + \left[\frac{y}{2} + \omega\bullet\left(\frac{(1+\alpha)\bullet\gamma\bullet(32+3.76\bullet 28)}{18}\right) + \frac{Mcdb}{18}\right]H_2O$$

Where:
$x = CA/12$
$y = HY$
$z = OX/16$
$\gamma = (x + \frac{y}{4} - \frac{z}{2})$
$\alpha =$ excess air parameter, e.g. if $\alpha =$ 0.5 there is 50 % excess air

From this:

$$PPMco = \frac{1E6\cdot\beta}{x + \left(\alpha\cdot\gamma + \frac{\beta}{2}\right) + (1+\alpha)\cdot\gamma\cdot 3.76}$$

$$PCTCO2 = \frac{100 \cdot (x-\beta)}{x + \left(\alpha \cdot \gamma + \frac{\beta}{2}\right) + (1+\alpha) \cdot \gamma \cdot 3.76}$$

With flue gas CO and CO_2 measured, these two equations can be solved simultaneously for β and α.

$$\beta = \frac{100 \cdot x \cdot PPMco}{1E6 \cdot PCTCO2 \cdot + 100 \cdot PPMco}$$

$$\alpha = \frac{\frac{100 \cdot (x-\beta)}{PCTCO2} - x - \frac{\beta}{2} - 3.76 \cdot \gamma}{4.76 \cdot \gamma}$$

<u>Calculation of the Molar Coefficient for Each of the Products</u>
For the assumption of 100 kg of dry fuel, this is the number of moles of each product for the input conditions

$MFCO = \beta$ Molar Coefficient for CO
$MFCO2 = x - \beta$ Molar Coefficient for CO_2
$MFH2O = \frac{\gamma}{2} + \frac{Mcdb}{18} + \frac{\omega \cdot (1+\alpha) \cdot \gamma \cdot (32 + 3.76 \cdot 28)}{18}$ Molar Coefficient for H_2O
$MFO2 = \alpha \cdot \gamma + \frac{\beta}{2}$ Molar Coefficient for O_2
$MFN2 = (1+\alpha) \cdot \gamma \cdot 3.76$ Molar Coefficient for N_2

<u>Heat Capacity of Exhaust Products</u>

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

$$C = A \cdot Tk + B$$

Where:
C = heat capacity J/mol K or kJ/kgmol K
A and B are constants
Tk = Temperature in °K

The values for A and B for the exhaust components are provided in the table below

Component	A	B
CO	.0056	27.162
CO2	.029	29.54
H2O	.0057	32.859
O2	.009	26.782
N2	.0062	26.626

For each component, heat capacity is calculated at the stack temperature and at room temperature. The average of these is used to calculate sensible heat loss.

<u>Calculation of Heat Losses for Efficiency Determination</u>

$HHVJ = HHV \cdot 2.326$ Higher heating value in kJ/kg (conversion from Btu/lb)
$LHWV = 43969$ Latent heat of water vapor in kJ/kgmol

$Llat = MFH2O \cdot LHWV \,/\, HHVJ$ Heat loss in latent heat of water vapor, % of input energy
$Lco = MFCO \cdot 282993 / HHVJ$ Heat loss in chemical energy in CO, % of input energy
$Lsens = (MFCO \cdot C\_COm + MFCO2 \cdot C\_CO2m + MFH2O \cdot C\_H2Om + MFO2 \cdot C\_O2m$
$+ MFN2 \cdot C\_N2) \,/\, HHVJ$ Heat loss in sensible heat in flue gas, % of input energy

$Efficiency = 100 - Llat - Lco - Lsens$ Stack loss efficiency, %

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

12.4.1. Introduction

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

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

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

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

12.4.1.5. A list of participants who participated witnessed the certification testing, participants involved in any research effort to include the development of the stove or development of instructions to guide certification testing, or User Guide instructions. This list shall specify their roles and observers present for the tests. The list shall include the participant's name, title, company, contact information and the purpose of their participation.

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

12.4.2. Summary and Discussion of Results

12.4.2.1. Table of results to include test run number, average burn rate for entire run, particulate emission rate for full run, particulate emission rate for start-up, carbon monoxide emission rate for the full run, carbon monoxide for startup, efficiency, burn time – total and by phase.

12.4.2.1.1. For each test run use the TEOM to apportion filter PM data and use real-time analyzer data for other emissions to report: Θ_1,Θ_2, Θ_3, CO, CO_2, PM, and efficiency for (1) the start-up phase and (2) high-, (3) maintenance-, and (4) overnight-fire phases. Calculated results for the emissions reported as total emissions in grams, pounds per million Btu output, grams per MJ, grams per kilogram of dry fuel and grams per hour, and pounds per hour.

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

12.4.2.1.3. A plot of CO emission rate in grams/minute vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

12.4.2.1.4. A plot of CO_2 emission rate in grams/minute vs. time, based on 1-minute averages, for the entire test period, for each run. The report shall include a table reporting the maximum 1-minute, 5-minute, and 60-minute grams per hour on a rolling basis for the test run.

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

12.4.2.1.6. Summary of other data – test facility conditions, surface temperature averages, catalyst averages, pretest fuel weights, test fuel charge weights – total and by phase.

12.4.2.2. Discussion. Test run result, specific test run problems and solutions.

12.4.2.3. Process description:

12.4.2.3.1. Data and drawings indicating the firebox size and location of the fuel charge.

12.4.2.3.2. Drawings and calculations used to determine firebox volume to include volume, height, width, and lengths, weight, and volume adjustments.

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

12.4.2.3.4. Process operation during the test – shall supply details on air supply settings and adjustments.

12.4.2.3.5. Test fuel properties – the report shall provide information on the species, density, fuel moisture, fuel temperature, and load details from the fuel load calculator to include all measurements including the number of pieces, individual piece weights, piece length, moisture content and weight.

12.4.2.4. Sampling

12.4.2.4.1. A description of the test procedures and test equipment, including a schematic or other drawing showing the location of all required test equipment. Also, a description of test fuel sourcing, handling and storage practices shall be included.

12.4.2.4.2. Describe the sampling location relative to the wood heater, include drawing or photographs.

12.4.2.4.3. Provide data on sampling blanks.

12.4.2.5. Quality Control and Assurance Procedures

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

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

12.4.2.6. Appendices

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

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

12.4.2.6.3. Sampling and Analytical Procedures. A detailed description of procedures followed by laboratory personnel in conducting the certification test.

12.4.2.6.4. Calibration Results. Summary of all calibrations, check, and audits pertinent to the certification.

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

12.4.2.6.6. User Guide. Appliance instructions for operating the device during the test following the User Guide specifications detailed in Section 8.1.1.

12.4.2.6.7. Test Facility Information. Report test facility temperature, air velocity, and humidity information.

12.4.2.6.8. 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.

12.4.2.6.9. Pre-test procedures. Report all pretest procedures conducted at the lab on the appliance to burns, rates, and amounts.

12.4.2.6.10. 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 shall be provided along with an analysis as to why these elements had no impact.

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

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

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

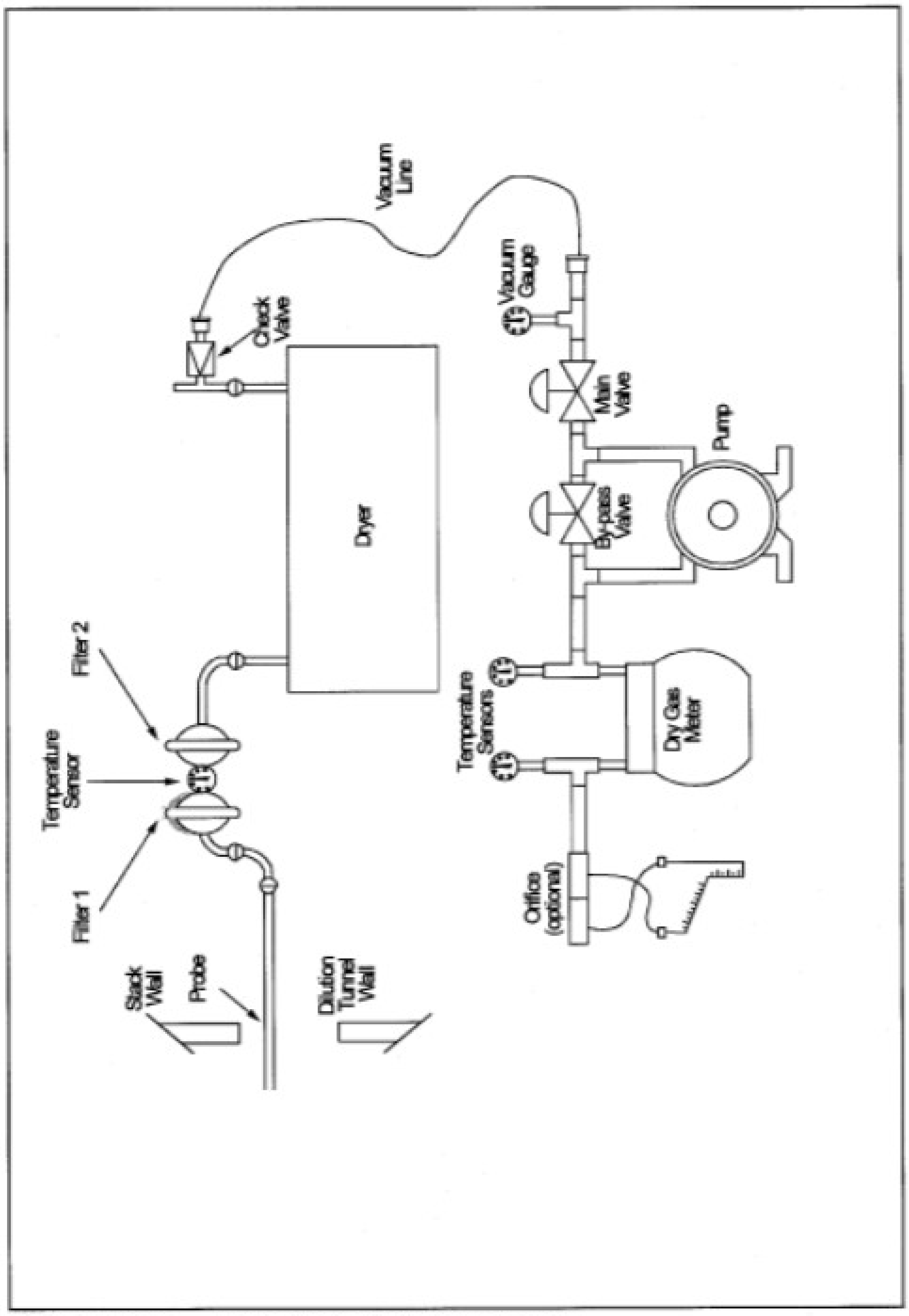


Figure 5G-1. Method 5G Sampling Train.

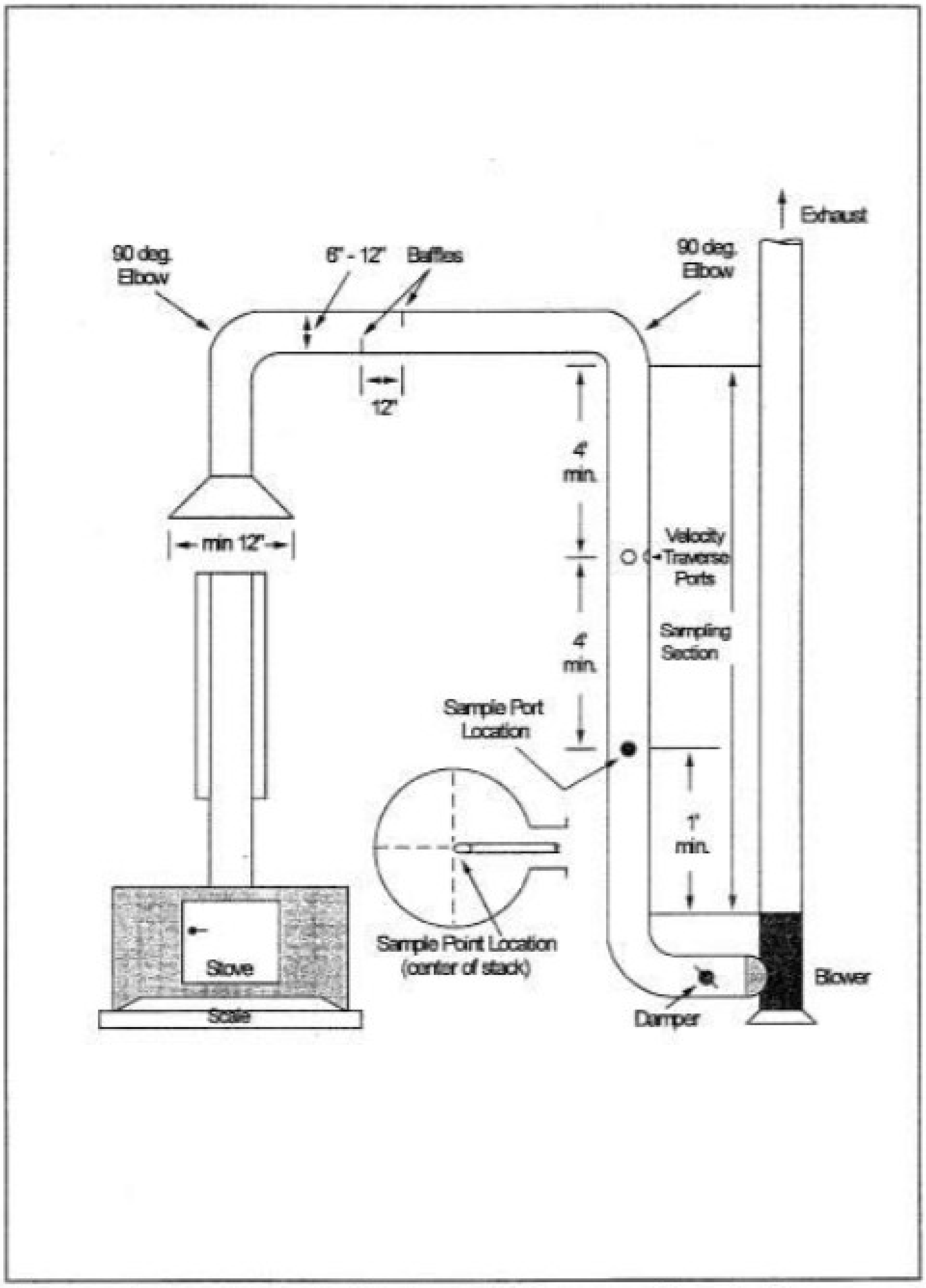


Figure 5G-2. Suggested Construction Details of the Dilution Tunnel.

Appendix A. Standard Operation Procedures for Thermo 1405 TEOM® for use in a dilution tunnel

Section 1. Introduction

This document covers operation concepts and procedures for use of the TEOM model 1405 to measure and report continuous particulate matter (PM) measurements in EPA Method 5G dilution tunnel or equivalent dilution method. The Thermo-Scientific model 1405 TEOM is designed for ambient real-time PM measurements. It is an inertial microbalance - a true continuous mass measurement method with resolution of 0.01 µg (0.00001 mg). The TEOM is highly configurable, allowing the instrument to be "tuned" to best meet the needs of a specific application. The version of the TEOM used here is the simplest, without any sample conditioning options such as "SES" or "FDMS". For dilution tunnel PM measurements, the TEOM flows, temperatures, and timing settings are changed from the normal ambient settings. There are no hardware modifications needed. Instrument manuals, software, and related support information are available from the NESCAUM TEOM document collection.[1]

Flow Setting

Recommended flow setting is 0.5 liters per minute (lpm) at EPA STP. If very low tunnel PM concentrations consistently less than 5 mg/m^3 are expected, higher settings of 1 to 3 lpm can be used. Higher flow gives better sensitivity but shorter filter life. The flow settings should be set to provide the needed sensitivity but also ensure reasonable filter life. For appliances where heavy loading is anticipated, a setting of 0.5 lpm shall be used. Appliances with lighter PM loading can use a setting of 1 or 2 lpm depending on the intended use of the data; high time resolution (10 seconds instead of 1 minute) requires higher flows to achieve the same sensitivity. The TEOM flow must be constant during a test run – it can not be changed while sampling.

Filter Temperature Zones Settings

The three TEOM filter temperature zones are normally set to 30 C (86 F). Temperatures can be set somewhat higher if laboratory temperature is expected to be over 80 F, but no higher than 33C (91F). Temperatures can not be changed during a sampling run. The TEOM filter temperature setting is always a trade-off between stability during highly dynamic burn conditions, minimizing loss of semi-volatile organic carbon mass, and avoiding condensing conditions at the filter temperature. Water is considered a semi-volatile mass (SVM) component, but standard practice is to minimize the amount of water measured as part of the PM. Based on

1 The TEOM manual is referenced in this SOP, and is available here: https://www.thermofisher.com/order/catalog/product/TEOM1405
Additional support documents are at https://drive.google.com/open?id=0B4duMFtoHVUENk9uemxsbHRJczA

current data, 30 C represents an appropriate setting assuming the dilution tunnel air dewpoint is controlled within reasonable limits (less than 30C).

TEOM Filter Dynamics

Rapid changes in the sample matrix (PM, gases, water vapor) may result in transient TEOM PM (positive or negative) concentration excursions. This is not an instrument malfunction; it is a result of the mass dynamics occurring on both the TEOM and filter pull filters. The TEOM filter material (Emfab TX40), temperature (30 C), and filter loading are similar to the gravimetric sample train rate (the TEOM filter face velocity is 6.3 cm/sec at 0.5 lpm). Thus, the filter pull PM and TEOM PM measurements should be in agreement and highly correlated if both sampling systems are working properly.

While TEOM PM transients from filter dynamics are usually no longer than 1 or 2 minutes, there can be situations where these filter dynamics can result in data quality issues for an extended period of time. One example is a very rapid transition (a few minutes) from a very dirty burn (as much as 300 mg/m^3 in the tunnel) to a very clean burn (a few mg/m^3 or less), as experienced with some devices during startup or fuel reloads. For that scenario, it may be necessary to change the TEOM filter after a high loading phase to avoid a prolonged period of a large negative bias to the TEOM PM due to loss of SVM off of the filter from the high loading phase. See Section 6 for more information on when to do pre-emptive filter changes (filter changes done to prevent or minimize negative TEOM data).

The TEOM configuration used here allows for fast filter changes with minimal data loss (typically a few minutes) and does not require flows and temperatures to be within predefined instrument limits for valid data for PM concentrations to be reported. Critical instrument parameters are stored with the concentration data and can be used to invalidate data during review and processing as needed.

Instrument Software

RPComm (serial port interface) is the legacy TEOM program and can be used to display the last 15 minutes of data on a graph, download data, and read all key operating parameters easily. The ePort program (ethernet interface) is used to control the instrument remotely and to download data. Both programs can be used at the same time.

Section 2. Overview of Routine Operation Procedures for Thermo 1405 TEOM

This section is a summary of routine operating procedures.

A. *Quality Assurance checks to be completed after initial installation, and routinely every 6 months:*

1. Modify system settings as detailed in Section 10
2. Perform KO check detailed in Section 5
3. Perform leak check detailed in Section 5

B. *Routine procedures before every test run to be conducted 2-3 hours prior to testing.*

1. Set TEOM filter temperature for the run. Changing this setting requires at least one hour before valid data can be collected. Detailed instructions on this element can be found in Section 3.
   a. The TEOM filter temperature must be at least 1 C above the hottest lab temperature expected during the test. The normal setting is 30 C (84 F) but may be set as high as 33 C (91 F).
   b. All three (3) temperatures zones - cap, air, case – must be set to the same value.

2. Set TEOM flow settings for the run. Changing this setting requires at least one hour before valid data can be collected. Detailed instructions on this element can be found in Section 4. TEOM flow can only be changed before a test run – it can not be changed during a run when the TEOM is sampling.
   a. Set flow
      i. Anticipated tunnel concentrations >5 mg/m^3: 0.5 lpm
      ii. Anticipated tunnel concentrations <5 mg/m^3: 1-3 lpm
   b. Calibrate TEOM flows. This step must be completed whenever the flow is changed. An external mass flow meter such as the TSI 4140 is used for flow calibrations.

3. Check the TEOM time and set as needed.
   Changing the time causes an instrument reboot and loss of up to an hour of data. See note below.

4. Initial filter change
   a. Install a clean filter before each run.
   b. Use the "Advanced" filter change mode.
   c. Perform an external flow check with the clean filter or before the start of a run.
   d. The net flow reading shall be within 2% of the TEOM flow setpoint.

C. *One hour before testing*

Check TEOM settings for appropriate temperature, flow and time settings. Perform an external flow check as detailed in Section 4 and record the results. For valid results the flow check should be within 2% of the TEOM flow setpoint.

D. *Testing Operations*

1. Before initiating the test, run the TEOM while sampling dilution tunnel air for at least 5 minutes. The change of pressure in the tunnel can cause a transient TEOM response.

2. Filter Changes are done pre-emptively as described in Section 6 and whenever the TEOM filter loading reaches 130%, as reported on the TEOM, or when the sample flow starts to drop. The 1405 does NOT have any clear visual warning that the filter needs changing, but it is possible to use the TEOM digital outputs (relay contact closures) to trigger an external alarm at any desired filter loading.

   The "Advanced" filter change wizard mode shall be used to eliminate long equilibration period after the change; this stops the tapered element oscillation, resets the filter mass measurement, and simplifies filter changes. Detailed information on performing filter changes during testing is provided in Section 6 of this document.

3. At the end of the test perform an external flow check as detailed in Section 4 and record the result. For valid results flow check should be within 2% of the TEOM flow setpoint.

4. Download the test data using either the Thermo ePort software (preferred), RPComm, or to a USB thumb drive. Note: the data format may be different depending on how the data is downloaded.

<u>Notes:</u>

- It is normal for there to be "Warnings" present for the ambient T/RH sensors (not used). This is the only allowable warning once the system is warmed up and is in use for testing.

- When the TEOM is first turned on or rebooted, <u>no data are recorded</u> until the top of the next hour. If TEOM is not rebooted, data will be recorded regardless of instrument status.

- When the time is changed, the instrument reboots (after many seconds of being hung, with no information on the screen). When it reboots, <u>no data are recorded</u> until after the top of the next hour (see above).

- TEOM PM concentrations are in micrograms per cubic meter, at EPA STP (25C and 1 atmosphere) unless the instrument configuration is changed. Filter mass loading is in micrograms.

Section 3. Filter Temperature Adjustment SOP for 1405 TEOM

The TEOM filter temperature has the capacity to be set between 30 and 55 degrees C, however for testing purposes, the filter temperature should be set to between 30 and 33 C. If the temperature is too low (less than 1 C above room temperature), the instrument may not be able to maintain the temperature set-point, possibly resulting in loss of data. Temperatures higher than necessary may result in excessive loss of semi-volatile PM during sampling. There are three temperature settings - cap, air, case – that shall all be set to the same value.

<u>Temperature Change Procedure.</u>
The TEOM temperatures are set in the Instrument Conditions, Temperatures menu. Temperatures can not be changed during a sampling run.

Note: The **T-Air** temperature zone may take a very long time (30 minutes or more) to stabilize, especially when the temperature is higher than the setpoint. If the "Case" temperature is within 0.1 C of the setpoint, data are usually valid.

Section 4. Sample Flow Check and Adjustment for the Thermo 1405 TEOM

<u>Checking the Sample Flow.</u>
The TEOM should be warmed up for at least 30 minutes before checking or adjusting the sample flow. The sample flow can not be changed during a test run. The sample flow should be checked at the sensor inlet with an external mass flow meter that reads in STP; that flow should be within 2 % of the flow on the TEOM display. Flow checks must be done:

A. at the start of every sampling day (with a clean filter),
B. at the end of the run (with the dirty filter), and
C. whenever the flow setting is changed.

Record the external flowmeter reading without flow as the zero and subtract that value from the flowmeter reading with flow to get the measured flow value.

If the post-test flow check (with a loaded filter) is lower than the initial flow check (with a clean filter), that is an indication of a possible leak. A leak test should also be performed whenever the flow check difference (between the TEOM display flow and the external flow meter flow) changes.

If the external flow (at EPA STP, with zero offset correction) is more than 5% off from the TEOM display flow, measure the flow without a filter in the TEOM. If the external flow check result is low with a filter but higher or correct without a filter, that is an indication of a leak.

If the flow is the same with and without a filter and out of spec, the flow calibration routine should be performed. This routine should also be performed whenever the sample flow setting is changed.

Flow settings.
The TEOM sample flow can be set to between 0.5 and 3.0 LPM (all flows are at EPA STP of 1 atm. and 25 C). Lower flow gives longer filter lifetime and less sensitivity. Higher flow gives shorter filter lifetime and more sensitivity. The flow should be set to provide reasonable filter lifetime (typically at least 30 minutes) for any given test scenario, since about 4 minutes of data are lost when the filter is changed.

For most cases when sampling off a dilution tunnel, the flow should be set to 0.5 LPM. If a high loading burn (tunnel PM greater than 20 mg/m^3) is anticipated, the flow must be set to 0.5 LPM. Flows higher than 1 LPM shall only be used when very light loading is expected (tunnel PM consistently below 2 to 3 mg/m^3).

The sample flow is set in Instrument Conditions, Flows, Flow Rates. Flow is calibrated using the wizard at Service, Calibration, Flow Calibration (page 5-39 of the TEOM manual).

NOTE: The TEOM sample flow cannot be changed during a test run.

Section 5. Leak Test and KO Check Procedure for 1405 TEOM

The Leak Test and K0 Checks described here do not need to be done on a routine basis. They should be done at least every 6 months, or as needed for troubleshooting.

Leak Check
A leak test measures the flow as reported by the TEOM's flow sensor with the inlet closed off. The TEOM leak test flow measurement must be corrected for the TEOM flowmeter's zero offset. To conduct a flow check, follow the procedures below:

1. With the TEOM warmed up for at least 30 minutes, read the TEOM reported flow with the pump turned off. This is the flowmeter zero reading.
2. Close off the inlet to the TEOM with a brass swage cap.
3. Turn on the TEOM pump.
4. Wait one minute and read the TEOM flow.
5. The leak test value is the difference between the reading without and with the pump on.
6. The leak test should be no greater than 0.05 lpm (net value).
7. Turn the pump off and remove the brass swage cap from the TEOM inlet.

K0 Check
In addition to routine pre- and post-sampling flow checks, a K0 check is another test that shall be completed to validate proper operation of the TEOM. K0 checks confirm the calibration factor for the tapered element mass transducer. It is done once per year and as needed. See page 5-50 of the manual.

Section 6. Filter Change Procedure for 1405 TEOM

The TEOM measures the pressure drop across the filter as % of maximum (~ 100 to 130 %), shown on the instrument=s display. A clean filter has a loading of about 5% at 0.5 LPM and ~ 7% at 1 LPM. Filter lifetime will vary widely depending on the PM concentrations being sampled. At very high PM concentrations (several hundred mg/m^3), filter lifetime may be only 10 to 15 minutes. Under typical sampling conditions, lifetime is at least 30 minutes and up to an hour or more with concentrations in the 20 to 50 mg/m3 range. With care, filter changes can be done such that only a few minutes of data are lost.

The TEOM filter must always be changed before the filter mass loading becomes too high and the filter plugs and the sample flow drops. TEOM filters can also be changed before they overload to minimize negative data.

There are three TEOM filter change scenarios for different applications:

1. EPA Method 5G or ASTM E2515 is the primary data source [the regulatory methods]. Teom data are used to parse the emission profile in the context of % attribution of full run regulatory filter data as described in Section 9. TEOM filters are normally only changed to prevent plugging. For this purpose, negative Teom data should be set to 0 in the final data set.

2. TEOM data are the primary data source.
The Teom filter gets changed whenever ANY of the following conditions are met. This minimizes negative or negatively biased Teom PM measurements.
2a. Filter plugs
2b. Filter mass loading exceeds 1000 ug AND the filter has been in use for at least 30 minutes. [both conditions have to be met]
2c. Persistent (at least several minutes) negative data of at least -2 mg/m^3 is observed that is not due to instrument noise when concentrations are very clean.

3. Validation of Teom PM against the regulatory filter PM methods under carefully controlled conditions.
This is a special case for method validation only, and is covered in Section 7. This is not for routine sampling.

<u>Filter change procedure.</u>

The following are filter handling procedures that shall be followed:

A. Unused clean filters should be stored in the original box, with the silica gel desiccant.
B. Two clean filters should be stored in the mass transducer.
C. Filters should only be handled with the filter change tool that is stored inside the TEOM cabinet.

The TEOM manual has illustrated procedures for filter changes starting on page 5-6. Try to minimize the time the mass transducer is open to minimize the time needed to re-stabilize after the filter change.

1. The filter change menu can be located by pushing the Service, Maintenance, Replace Filter. Select Advanced option, and then Next to proceed.

2. Open the TEOM cabinet door, open the box of clean filters, and open the mass transducer. Remove the old filter by sliding the filter tool onto the filter and pulling straight out. Do not twist the tool (to prevent damage to the glass tapered element).

3. Pick up a new filter (stored inside the mass transducer) with the tool. Position it directly over the tapered element and push the filter on gently. Once the filter is on, remove the tool from the filter and fully seat the filter by pushing firmly straight down on the filter with the bottom of the tool (see section 3 of the manual for more information). Store another new filter in the mass transducer.

4. Close the mass transducer, replace the filter box cover, and close the cabinet. Restart the TEOM by completing the filter change wizard.

5. If the PM concentration as read on the RPComm graph hasn't stabilized within 5 minutes, or if the Frequency is close to 0 (~10 instead of a few hundred Hz) the filter may need to be reseated or is defective, or the sensor latch is not closed properly. Repeat the filter change "advanced" procedure and take the filter off and re-seat it. Push it on firmly with the back of the filter tool and make sure the sensor is properly closed and latched. After two attempts, restart the procedure with another new filter.

Note: the PM concentration on the TEOM display will read 0 after a filter change until the top of the next hour. When valid data are being collected, the RPComm graph will indicate the concentration, and the "Total Mass" on the TEOM display will read something other than "0.00".

► <u>There is one exception to this:</u> after an instrument reboot for any reason (including setting the time), data are not stored until after the top of the next hour, even if the RPComm graph is showing data and the Total Mass is not 0.

Section 7. Filter Change Protocol for Method Validation: Matching Filter Pull and TEOM Filter Face Velocities and Mass Loadings for Control of semi-volatile mass loss.

This is a special case for method validation only, and is not used for routine sampling or regulatory testing. For this use, the filter pull and Teom filter face velocity, filter temperature, and filter mass loading are all closely matched to control for loss of semi-volatile PM components (SVOC and water). Since the filter media for both the filter pull and the Teom are the same (EMFAB TX40), if the filter face velocities and temperatures are properly matched, the mass loading should also be matched. Mass loading on the TEOM filter should not exceed 2.0 mg. The filter pull filter must be changed when the TEOM filter is changed. Start and end times of sampling on a filter must also be matched. This means that sample probes are put into and taken out of the dilution tunnel at the same time. The TEOM data must have stabilized after a filter change before sample probes are put into the tunnel. Filter pull filters must be weighed soon (< 2 hours) after each filter is finished sampling, and again after equilibration per the regulatory method.

Section 8: Data Storage and Download

The TEOM shall be set to store data every 10 seconds. There is storage for several days of data at this storage interval. Data can be downloaded while the TEOM is running.

Data are usually downloaded with the ePort software but if needed can also be downloaded to a USB thumb drive or with the RPComm TEOM software. The data file is in .CSV format for importing into a spreadsheet.

Data parameters are saved as follows:
1. Date, Time
2. PM-2.5 raw MC
3. PM-2.5 MC
4. PM-2.5 total mass
5. PM-2.5 30-Min MC
6. Operating mode
7. System status
8. PM-2.5 flow rate
9. PM-2.5 TEOM filter load
10. PM-2.5 TEOM filter pressure
11. Case temperature
12. Cap temperature
13. PM-2.5 air tube temperature
14. Enclosure temperature
15. PM-2.5 TEOM noise
16. PM-2.5 TEOM frequency
17. Vacuum pump pressure

The key parameters for data validation and analysis are:
1. Date and Time – reported as the end of the average interval
2. PM2.5 raw - PM2.5 raw is the same as PM2.5 MC except it is always reported even when the instrument status is invalid. This minimizes loss of data but also requires manual editing of the data file to remove invalid PM concentrations based on review of the data and critical parameters such as flow and temperatures. Concentration is in µg/m^3. A zero value for Mass Conc indicates no data.
3. PM2.5 total mass - the mass loading on the TEOM filter in µg.
4. PM2.5 flow rate - Flow is SLPM unless something else is used in the instrument

configuration.

5. PM2.5 TEOM filter load - filter loading as % of maximum.
6. Case temperature, in degrees C.
7. Noise is a data stability metric and should normally be less than 0.10 when pm concentrations are low or zero.

Section 9. Data Validation and Calculations

TEOM data are recorded every 10 seconds to minimize data loss during filter changes. Data validation is performed on the 10 second data and then usually averaged up to 1-minute intervals for reporting use.

TEOM data are valid when all flows and temperatures are within the defined operating ranges specified below.

1. "Case" temperature is stable and within 0.1 deg C of set-point. Other temperatures can be off as long as the Case temperature is stable and close to the set-point.
2. Flow reported by the instrument should be within 5% of the flow setpoint.

Because of the way the Teom is run here [with a wait time of 0], it never invalidates any data. Thus the data must always be reviewed and cleaned up manually. The wait time is set to 0 to minimize data loss during a filter change, or when the "Cap" temperature is out of range but the data are ok. The Teom reports a concentration of 0 or repeating values when there are no valid data.

The "Raw MC" PM concentration parameter is reported regardless of instrument conditions and thus includes invalid data that need to be removed during data validation. Normally the only data that need to be removed are during a filter change that occurs during a run. When a filter is changed, the last valid concentration value is repeated until new valid data are available. These repeating data are removed manually during validation and considered as "missing" data.

Note: For cumulative PM emission measurements (total grams of PM emitted during a burn phase or run), missing data shall be filled in with best-estimates based on the 1-minute PM concentrations immediately before and after the filter change. Otherwise, the effective emissions for the period with missing data are zero, creating a negative bias in the measurement.

It is common for the TEOM PM concentration to be somewhat negative during some burn phases. This happens when the TEOM filter mass loading is large and PM emissions are relatively low (e.g., for a clean burn phase that follows a dirty burn phase), and the TEOM filter loses mass. This can be controlled by pre-emptive filter changes as described in Section 6. Small negative concentration up to a few mg/m^3 can still occur however. To minimize measurement bias, these small negative concentrations should always be set to 0 during data processing. Large and rapid negative data swings in concentration may indicate a problem with the instrument and should normally be considered invalid or missing data (not set to 0).

The output of the TEOM is PM concentration in the dilution tunnel, in µg/m^3 at 25 C and 1 Atmosphere (29.92 inches Hg) pressure. To correct TEOM data to the test or reporting conditions use the following:

PM at local T and P = PM at STP * (298/T) * (P/29.92)

The 1-minute TEOM PM concentration is converted into grams/hour using the tunnel flow as follows:

g/h = 0.000001699 * tunnel flow (in CFM) * PM concentration (in µg/m^3)

The values used for tunnel flow shall be the actual measured values, at intervals of no greater than 10 minutes. If the range of 10 minute tunnel flow measurements [100*(Max - Min) / average] is no greater than 5% of the run-average tunnel flow, the run average tunnel flow can be used for these calculations.

TEOM data can be used to apportion the PM emission rate (g/h) measured by a Method 5G or E2515 regulatory sample train to multiple burn phases by applying a correction factor to the 1-minute Teom data. The correction factor is the ratio of filter pull full run g/h to TEOM full run g/h. The 1-minute TEOM data is then adjusted by this correction factor.

Note: since actual measured tunnel flows are used to convert TEOM data into g/h, tunnel flow does not need to be controlled other than what is necessary to maintain proportionality between tunnel flows and regulatory method filter flows.

For calculation of lbs/mmbtu, total grams PM emitted is calculated by multiplying the average g/h rate for the test period of interest times the number of hours of that test period. Grams are converted to lbs by multiplying grams by 453.6.

Section 10: TEOM Configuration Changes for Fast Response and High PM Concentrations, and List of TEOM Parameter Configuration Values.

These settings are for the 1405 TEOM as used in this application that are different from instrument default settings. See the 1405 manual for detailed information on how to change these values.

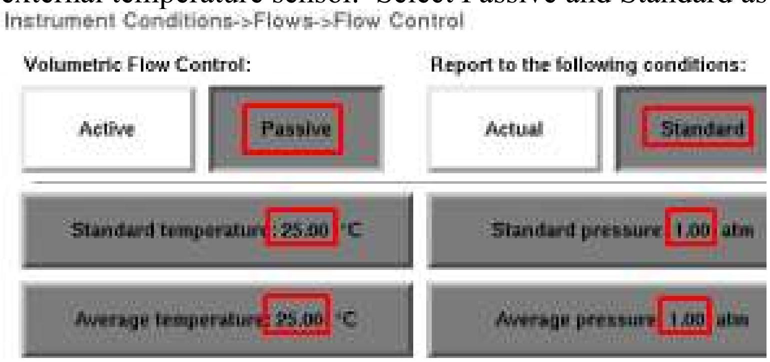
1. Remove the A and B factors [+3 and x1.03] that are used for PM10 FEM status. “Mass Constant A” is set to zero, and “Mass Constant B” is set to 1.00.

2. Change system filtering and wait time settings:
TM (Total Mass Avg time) from 300 to 15 seconds
MR-MC (Mass Rate/Mass Conc Avg time) from 300 to 15 seconds
Wait Time from 1800 to 0 seconds (disabled)

3. Change the sample flow from 3.0 to 0.5 lpm. The bypass flow is set to 0.

4. Change all 3 temperature zones [Case, Air, Cap] to 30 C.

5. Set both the “Avg” and “Std” T/P to 25 C / 1 atm - this is the default for systems without the external temperature sensor. Select Passive and Standard as shown below.



6. Change the Data Storage interval to 10 seconds.

A complete list of 1405 TEOM Settings that are modified from instrument defaults are listed below:

PRC	Description	Config Value	Unit		
12	storage interval	10	sec		
28	system wait time	0	sec		
35	mass average time	15	sec	See also PRC392 -- MRMC	
48	case temperature set point	30	Deg C or higher as needed to maintain a stable case T		See also PRC 115 -- air tube T
59	cap temperature set point	30	Deg C or higher as needed to maintain a stable case T		
74	average temperature set point	25	C	These are for reporting PM at EPA STP	
75	standard temperature set point	25	C	These are for reporting PM at EPA STP	
76	average pressure set point	1	atm	These are for reporting PM at EPA STP	
77	standard pressure set point	1	atm	These are for reporting PM at EPA STP	
91	bypass flow mass set point	0		Can be used as a baseline param for rpcomm plots.	
115	TEOMA air tube set point	30	Deg C, or higher as needed to maintain a stable filter T; see also PRC 48 and 59.		
136	analog output1 minimum	-5000	optional -- ug/m3 as needed for RPComm plot scaling		
144	analog output1 maximum	50000	optional -- ug/m3 as needed for RPComm plot scaling		
227	TEOMA flow set point	1	lpm; or 0.5 to 2 lpm as needed; flow must be recalibrated if changed!		
392	MRMC average time	15	sec		
407	TEOMA mass constant A	0			
408	TEOMA mass constant B	1			
	Note: all 3 temperatures must be set to the same value.				

Data Logging Parameters.

prc	description	var name in data file	Unit
244	raw mass conc	TEOMAMCRaw	ug/m3
245	mass conc	TEOMAMC	ug/m3
243	total filter mass loading	TEOMATotalMass	ug/m3
7	operating mode	OperatingMode	#
8	system status	StatusCondition	#
225	flow rate (STP)	TEOMAFlowMass	lpm
241	filter pressure	TEOMAFilterPressure	raw
242	filter load %	TEOMAFilterLoad	% of max
47	case temperature	CaseHeatTemp	C
58	cap temperature	CapHeatTemp	C
237	air tube temperature	TEOMAAirTubeHeatTemp	C
258	noise	TEOMANoise	ug
257	frequency	TEOMAFrequency	Hz