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## **METHOD 28A - MEASUREMENT OF AIR-TO-FUEL RATIO AND MINIMUM ACHIEVABLE BURN RATES FOR WOOD-FIRED APPLIANCES**

Note: This method does not include all or the specifications (*e.g.*, equipment and supplies) and procedures (*e.g.*, sampling and analytical) essential to its performance. Some material is incorporated by reference from other methods in this part. Therefore, to obtain reliable results, persons using this method should also have a thorough knowledge of at least the following additional test methods: Method 3, Method 3A, Method 5H, Method 6C, and Method 28.

### *1.0 Scope and Application*

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

1.2 Applicability. This method is applicable for the measurement of air-to-fuel ratios and minimum achievable burn rates, for determining whether a wood-fired appliance is an affected facility, as specified in 40 CFR 60.530.

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.

### *2.0 Summary of Method*

2.1 A gas sample is extracted from a location in the stack of a wood-fired appliance while the appliance is operating at a prescribed set of conditions. The gas sample is analyzed for carbon dioxide (CO<sub>2</sub>), oxygen (O<sub>2</sub>), and carbon monoxide (CO). These stack gas components are measured for determining the dry molecular weight of the exhaust gas. Total moles of exhaust gas are determined stoichiometrically. Air-to-fuel ratio is determined by relating the mass of dry combustion air to the mass of dry fuel consumed.

### *3.0 Definitions*

Same as Method 28, Section 3.0, with the addition of the following:

3.1 Air-to-fuel ratio means the ratio of the mass of dry combustion air introduced into the firebox to the mass of dry fuel consumed (grams of dry air per gram of dry wood burned).

### *4.0 Interferences[Reserved]*

### *5.0 Safety*

5.1 Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all of 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.

### *6.0 Equipment and Supplies*

6.1 Test Facility. Insulated Solid Pack Chimney, Platform Scale and Monitor, Test Facility Temperature Monitor, Balance, Moisture Meter, Anemometer, Barometer, Draft Gauge, Humidity Gauge, Wood Heater Flue, and Test Facility. Same as Method 28, Sections 6.1, 6.2, and 6.4 to 6.12, respectively.

6.2 Sampling System. Probe, Condenser, Valve, Pump, Rate Meter, Flexible Bag, Pressure Gauge, and Vacuum Gauge. Same as Method 3, Sections 6.2.1 to 6.2.8, respectively. Alternatively, the sampling system described in Method 5H, Section 6.1 may be used.

6.3 Exhaust Gas Analysis. Use one or both of the following:

6.3.1 Orsat Analyzer. Same as Method 3, Section 6.1.3

6.3.2 Instrumental Analyzers. Same as Method 5H, Sections 6.1.3.4 and 6.1.3.5, for CO<sub>2</sub> and CO analyzers, except use a CO analyzer with a range of 0 to 5 percent and use a CO<sub>2</sub> analyzer with a range of 0 to 5 percent. Use an O<sub>2</sub> analyzer capable of providing a measure of O<sub>2</sub> in the range of 0 to 25 percent by volume at least once every 10 minutes.

### *7.0 Reagents and Standards*

7.1 Test Fuel and Test Fuel Spacers. Same as Method 28, Sections 7.1 and 7.2, respectively.

7.2 Cylinder Gases. For each of the three analyzers, use the same concentration as specified in Sections 7.2.1, 7.2.2, and 7.2.3 of Method 6C.

### *8.0 Sample Collection, Preservation, Storage, and Transport*

8.1 Wood Heater Air Supply Adjustments.

8.1.1 This section describes how dampers are to be set or adjusted and air inlet ports closed or sealed during Method 28A tests. The specifications in this section are intended to ensure that affected facility determinations are made on the facility configurations that could reasonably be expected to be employed by the user. They are also intended to prevent circumvention of the standard through the addition of an air port that would often be blocked off in actual use. These specifications are based on the assumption that consumers will remove such items as dampers or other closure mechanism stops if this can be done readily with household tools; that consumers will block air inlet passages not visible during normal operation of the appliance using aluminum tape or parts generally available at retail stores; and that consumers will cap off any threaded or flanged air inlets. They also assume that air leakage around glass doors, sheet metal joints or through inlet grilles visible during normal operation of the appliance would not be further blocked or taped off by a consumer.

8.1.2 It is not the intention of this section to cause an appliance that is clearly designed, intended, and, in most normal installations, used as a fireplace to be converted into a wood heater for purposes of applicability testing. Such a fireplace would be identifiable by such features as large or multiple glass doors or panels that are not gasketed, relatively unrestricted air inlets intended, in large part, to limit smoking and fogging of glass surfaces, and other aesthetic features not normally included in wood heaters.

8.1.3 Adjustable Air Supply Mechanisms. Any commercially available flue damper, other adjustment mechanism or other air inlet port that is designed, intended or otherwise reasonably expected to be adjusted or closed by consumers, installers, or dealers and which could restrict air into the firebox shall be set so as to achieve minimum air into the firebox (*i.e.*, closed off or set in the most closed position).

8.1.3.1 Flue dampers, mechanisms and air inlet ports which could reasonably be expected to be adjusted or closed would include:

8.1.3.1.1 All internal or externally adjustable mechanisms (including adjustments that affect the tightness of door fittings) that are accessible either before and/or after installation.

8.1.3.1.2 All mechanisms, other inlet ports, or inlet port stops that are identified in the owner's manual or in any dealer literature as being adjustable or alterable. For example, an inlet port that could be used to provide access to an outside air duct but which is identified as being closable through use of additional materials whether or not they are supplied with the facility.

8.1.3.1.3 Any combustion air inlet port or commercially available flue damper or mechanism stop, which would readily lend itself to closure by consumers who are handy with household tools by the removal of parts or the addition of parts generally available at retail stores (*e.g.*, addition of a pipe cap or plug, addition of a small metal plate to an inlet hole on a nondecorative sheet metal surface, or removal of riveted or screwed damper stops).

8.1.3.1.4 Any flue damper, other adjustment mechanisms or other air inlet ports that are found and documented in several (*e.g.*, a number sufficient to reasonably conclude that the practice is not unique or uncommon) actual installations as having been adjusted to a more closed position, or closed by consumers, installers, or dealers.

8.1.4 Air Supply Adjustments During Test. The test shall be performed with all air inlets identified under this section in the closed or most closed position or in the configuration which otherwise achieves the lowest air inlet (*i.e.*, greatest blockage).

Note: For the purposes of this section, air flow shall not be minimized beyond the point necessary to maintain combustion or beyond the point that forces smoke into the room.

8.1.5 Notwithstanding Section 8.1.1, any flue damper, adjustment mechanism, or air inlet port (whether or not equipped with flue dampers or adjusting mechanisms) that is visible during normal operation of the appliance and which could not reasonably be closed further or blocked except through means that would significantly degrade the aesthetics of the facility (*e.g.*, through use of duct tape) will not be closed further or blocked.

8.2 Sampling System.

8.2.1 Sampling Location. Same as Method 5H, Section 8.1.2.

8.2.2 Sampling System Set Up. Set up the sampling equipment as described in Method 3, Section 8.1.

8.3 Wood Heater Installation, Test Facility Conditions, Wood Heater Firebox Volume, and Test Fuel Charge. Same as Method 28, Sections 8.4 and 8.6 to 8.8, respectively.

8.4 Pretest Ignition. Same as Method 28, Section 8.11. Set the wood heater air supply settings to achieve a burn rate in Category 1 or the lowest achievable burn rate (see Section 8.1).

8.5 Test Run. Same as Method 28, Section 8.12. Begin sample collection at the start of the test run as defined in Method 28, Section 8.12.1.

8.5.1 Gas Analysis.

8.5.1.1 If Method 3 is used, collect a minimum of two bag samples simultaneously at a constant sampling rate for the duration of the test run. A minimum sample volume of 30 liters (1.1 ft<sup>3</sup>) per bag is recommended.

8.5.1.2 If instrumental gas concentration measurement procedures are used, conduct the gas measurement system performance tests, analyzer calibration, and analyzer calibration error check outlined in Method 6C, Sections 8.2.3, 8.2.4, 8.5, and 10.0, respectively. Sample at a constant rate for the duration of the test run.

8.5.2 Data Recording. Record wood heater operational data, test facility temperature, sample train flow rate, and fuel weight data at intervals of no greater than 10 minutes.

8.5.3 Test Run Completion. Same as Method 28, Section 8.13.

## 9.0 *Quality Control*

9.1 Data Validation. The following quality control procedure is suggested to provide a check on the quality of the data.

9.1.1 Calculate a fuel factor,  $F_o$ , using Equation 28A–1 in Section 12.2.

9.1.2 If CO is present in quantities measurable by this method, adjust the O<sub>2</sub> and CO<sub>2</sub> values before performing the calculation for  $F_o$  as shown in Section 12.3 and 12.4.

9.1.3 Compare the calculated  $F_o$  factor with the expected  $F_o$  range for wood (1.000–1.120). Calculated  $F_o$  values beyond this acceptable range should be investigated before accepting the test results. For example, the strength of the solutions in the gas analyzer and the analyzing technique should be checked by sampling and analyzing a known concentration, such as air. If no detectable or correctable measurement error can be identified, the test should be repeated. Alternatively, determine a range of air-to-fuel ratio results that could include the correct value by using an  $F_o$  value of 1.05 and calculating a potential range of CO<sub>2</sub> and O<sub>2</sub> values. Acceptance of such results will be based on whether the calculated range includes the exemption limit and the judgment of the Administrator.

9.2 Method 3 Analyses. Compare the results of the analyses of the two bag samples. If all the gas components (O<sub>2</sub>, CO, and CO<sub>2</sub>) values for the two analyses agree within 0.5 percent (e.g., 6.0 percent O<sub>2</sub> for bag 1 and 6.5 percent O<sub>2</sub> for bag 2, agree within 0.5 percent), the results of the bag analyses may be averaged for the calculations in Section 12. If the analysis results do not agree within 0.5 percent for each component, calculate the air-to-fuel ratio using both sets of analyses and report the results.

## 10.0 *Calibration and Standardization[Reserved]*

*11.0 Analytical Procedures*

11.1 Method 3 Integrated Bag Samples. Within 4 hours after the sample collection, analyze each bag sample for percent CO<sub>2</sub>, O<sub>2</sub>, and CO using an Orsat analyzer as described in Method 3, Section 11.0.

11.2 Instrumental Analyzers. Average the percent CO<sub>2</sub>, CO, and O<sub>2</sub> values for the test run.

*12.0 Data Analyses and Calculations*

Carry out calculations, retaining at least one extra significant figure beyond that of the acquired data. Round off figure after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

12.1 Nomenclature.

$M_d$  = Dry molecular weight, g/g-mole (lb/lb-mole).

$N_T$  = Total gram-moles of dry exhaust gas per kg of wood burned (lb-moles/lb).

%CO<sub>2</sub> = Percent CO<sub>2</sub> by volume (dry basis).

%CO = Percent CO by volume (dry basis).

%N<sub>2</sub> = Percent N<sub>2</sub> by volume (dry basis).

%O<sub>2</sub> = Percent O<sub>2</sub> by volume (dry basis).

$Y_{HC}$  = Assumed mole fraction of HC (dry as CH<sub>4</sub>)=0.0088 for catalytic wood heaters;=0.0132 for noncatalytic wood heaters.=0.0080 for pellet-fired wood heaters.

$Y_{CO}$  = Measured mole fraction of CO (*e.g.*, 1 percent CO=.01 mole fraction), g/g-mole (lb/lb-mole).

$Y_{CO_2}$  = Measured mole fraction of CO<sub>2</sub> (*e.g.*, 10 percent CO<sub>2</sub>=.10 mole fraction), g/g-mole (lb/lb-mole).

0.280 = Molecular weight of N<sub>2</sub> or CO, divided by 100.

0.320 = Molecular weight of O<sub>2</sub> divided by 100.

0.440 = Molecular weight of CO<sub>2</sub> divided by 100.

20.9 = Percent O<sub>2</sub> by volume in ambient air.

42.5 = Gram-moles of carbon in 1 kg of dry wood assuming 51 percent carbon by weight dry basis (.0425 lb/lb-mole).

510 = Grams of carbon in exhaust gas per kg of wood burned.

1,000 = Grams in 1 kg.

12.2 Fuel Factor. Use Equation 28A-1 to calculate the fuel factor.

$$F_o = \frac{20.9 - \%O_2}{\%CO_2} \quad \text{Eq. 28A-1}$$

12.3 Adjusted %CO<sub>2</sub>. Use Equation 28A-2 to adjust CO<sub>2</sub> values if measurable CO is present.

$$\%CO_{2(a\ddot{a})} = \%CO_2 + \%CO \quad \text{Eq. 28A-2}$$

12.4 Adjusted %O<sub>2</sub>. Use Equation 28A-3 to adjust O<sub>2</sub> value if measurable CO is present.

$$\%O_{2(a\ddot{a})} = \%O_2 - 0.5\%CO \quad \text{Eq. 28A-3}$$

12.5 Dry Molecular Weight. Use Equation 28A-4 to calculate the dry molecular weight of the stack gas.

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO) \quad \text{Eq. 28A-4}$$

Note: The above equation does not consider argon in air (about 0.9 percent, molecular weight of 39.9). A negative error of about 0.4 percent is introduced. Argon may be included in the analysis using procedures subject to approval of the Administrator.

12.6 Dry Moles of Exhaust Gas. Use Equation 28A-5 to calculate the total moles of dry exhaust gas produced per kilogram of dry wood burned.

$$N_T = \frac{42.5}{(Y_{CO_2} + Y_{CO} + Y_{HC})} \quad \text{Eq. 28A-5}$$

12.7 Air-to-Fuel Ratio. Use Equation 28A-6 to calculate the air-to-fuel ratio on a dry mass basis.

$$A/F = \frac{(N_T \times M_d) - 510}{1,000} \quad \text{Eq. 28A-6}$$

12.8 Burn Rate. Calculate the fuel burn rate as in Method 28, Section 12.4.

13.0 *Method Performance[Reserved]*

14.0 *Pollution Prevention[Reserved]*

15.0 *Waste Management[Reserved]*

16.0 *References*

Same as Section 16.0 of Method 3 and Section 17 of Method 5G.

17.0 *Tables, Diagrams, Flowcharts, and Validation Data[Reserved]*