CONDITIONAL TEST METHOD (CTM-041) -- DETERMINATION OF VOLUMETRIC GAS FLOW IN RECTANGULAR DUCTS OR STACKS TAKING INTO ACCOUNT VELOCITY DECAY NEAR THE STACK OR DUCT WALLS

1.0   *Scope and Application*

This method may be applied when determining volumetric flow in rectangular stacks and ducts to account for velocity decay near the walls. 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 wall effects adjustment factor (WAF) is determined. The WAF is used to adjust the cross-sectional area value used to calculate volumetric flow based on reference method or continuous emission monitoring system (CEMS) gas velocity measurements to take into account velocity decay near the stack or duct walls.

2.2   The method contains a calculation approach to derive wall effects adjustment factors based on either measured velocities or a combination of measured and modeled velocities. The method also contains procedures to determine a duct or stack specific default based on conservative velocity estimates, requiring no additional velocity measurements. Unless a duct or stack specific default is used, any adjustment factor must be based on at least three wall effect test runs.

2.3   The wall effects test may be conducted as part of a relative accuracy test audit (RATA) or as a separate test procedure. Any WAF that is derived using this procedure can only be applied to calculate volumetric flows in conjunction with velocity values from RATAs consisting of the same number of Method 1 traverse points used to determine the WAF or from a CEMS for which such a RATA has been conducted. A wall effects test must be completed whenever the stack or ductwork is altered such that the flow profile is significantly changed.

3.0   *Definitions*

3.1   Reserved.

3.2 d_{last} means, depending on context, either (1) the distance from the wall of the last one-inch incremented wall effects traverse point or (2) the traverse point located at that distance (see Figure 2).

3.3 d_{rem} means, depending on context, either (1) the distance from the wall of the centroid of the area between d_{last} and the interior edge of the Method 1 equal-area sector closest to the wall or (2) the traverse point located at that distance (see Figure 2).

3.3.1 d_{rem_y} represents d_{rem} for the wall perpendicular to the test port wall (see Figure 2).

3.3.2 d_{rem_x} represents d_{rem} for the test port wall (see Figure 2).

3.3.4 d_{rem_c} represents d_{rem} for the Method 1 corner equal-area sector (see Figure 2).

3.3.5   Reserved.

3.3.6   Reserved.

3.4   *"May," "Must," "Shall," "Should,"* and the imperative form of verbs.

3.4.1   *"May"* is used to indicate that a provision of this method is optional.

3.4.2   *"Must," "Shall,"* and the imperative form of verbs (such as "record" or "enter") are used to indicate that a provision of this method is mandatory.

3.4.3   *"Should"* is used to indicate that a provision of this method is not mandatory but is highly recommended as good practice.

3.5   *Method 1* refers to 40 CFR Part 60, Appendix A, "Method 1-Sample and Velocity Traverses for Stationary Sources."

3.6   M*ethod 2* refers to 40 CFR Part 60, Appendix A, "Method 2-Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)."

3.7   *Method 2F* refers to 40 CFR Part 60, Appendix A, "Method 2F-Determination of Stack Gas Velocity and Volumetric Flow Rate with Three-Dimensional Probes."

3.8   *Method 2*G refers to 40 CFR Part 60, Appendix A, "Method 2G-Determination of Stack Gas Velocity and Volumetric Flow Rate with Two-Dimensional Probes."

3.9   *One-inch incremented wall effects traverse point* means any of the wall effects traverse points that are located at one-inch intervals, i.e., traverse points d_1 through d_{last} (see Figure 2).

3.10   *Opposing test port wall* means the wall that is parallel to the test port wall on the opposite side of the duct or stack.

3.11   *Relative accuracy test audit (RATA)* is a field test procedure performed in a stack or duct in which a series of concurrent measurements of the same effluent stream is taken by a reference method and an installed monitoring system. A RATA usually consists of a series of 9 to 12 sets of such concurrent measurements, each of which is referred to as a RATA run. In a volumetric flow RATA, each reference method run consists of a complete traverse of the stack or duct.

3.12   *Test port wall* means the wall of the duct or stack in which test ports are mounted

3.13   *Wall effects unadjusted average velocity* means the average gas velocity, not accounting for velocity decay near the wall, as determined in accordance with Method 2, 2F, or 2G for a Method 1 traverse.

3.14   *Wall effects adjusted average velocity* means the average gas velocity, taking into account velocity decay near the wall, as calculated from measurements at the Method 1 traverse points and at the additional wall effects traverse points specified in this method.

3.15   *Wall effects traverse point* means a traverse point located in accordance with Section 8.1.2 of this method.

4.0   *Interferences* [Reserved]

5.0   *Safety*

This method may involve hazardous materials, operations, and equipment. This method does not purport to address all of the health and safety considerations associated with its use. It is the responsibility of the user of this method to establish appropriate health and safety practices and to determine the applicability of occupational health and safety regulatory requirements prior to performing this method.

6.0   *Equipment and Supplies*

The provisions pertaining to equipment and supplies in the method that is used to take the traverse point measurements (i.e., Method 2, 2F, or 2G) are applicable under this method.

7.0   *Reagents and Standards* [Reserved]

8.0   *Sample Collection and Analysis*

8.1   *Traverse Point Locations and Measurements.* Conduct measurements at Method 1 and wall effects traverse points in accordance with Method 2, 2F, or 2G and Section 8.2 of this method. Determine the location of the Method 1 traverse points in accordance with Section 8.1.1, and the location of the wall effects traverse points in accordance with Section 8.1.2. The alternative procedures of Section 8.4 may be used in lieu of performing all the measurements specified in this section. All traverse points are determined with respect to the test ports used when conducting RATAs.

8.1.1   Method 1 equal-area traverse point locations. Determine the location of the Method 1 equal-area traverse points using Table 1-1 (Cross Section Layout for Rectangular Stacks) and the procedure described in Section 2.3.2 of Method 1.

8.1.2 Wall effects traverse point locations. Measurements must be taken at the following points from at least four test ports. Measurements may be taken from any available test port, provided that all measurements are made in the same test plane and that at least four test ports are used. For the purpose of this method, near wall measurements are excluded from test ports

where the flow is disturbed at a required traverse point located in the equal area nearest the test port wall because upstream cross-bracing (or some other disturbance) near the traverse location is directly in-line with the required traverse point. If necessary or desired, near wall measurements can be made from ports located on more than one duct wall.

    (a) One-inch increments from the wall. At least one increment point must be measured. Measurements may be taken at any number of additional one-inch increments, provided that each point must be located at a distance that is a whole number (e.g., 1, 2, 3) multiple of 1 inch (2.5 cm) from the wall and that no one-inch intervals are omitted between increments.

    (b) d_{rem_x}, as determined using Equation 1.

    (c) d_{rem_y}, as determined using Equation 3.

    (d) d_{M1_y}, the distance between the wall perpendicular to the test port wall and the centroid of the Method 1 exterior equal-area sector adjacent to that wall as determined using Equation 5.

    (e) d_{M1}, the distance of the first Method 1 equal area traverse point closest from the test port wall. Measurements need not be repeated if already required under Section 8.1.1.

    8.1.2.1 If the probe cannot be positioned at 1 in. (2.5 cm) from the wall (e.g., because of insufficient room to withdraw the probe shaft) or if the flue gas velocity cannot be measured at 1 in. (2.5 cm) from the wall because the port extends beyond the wall into the stack or duct, take measurements at the one-inch incremented wall effects traverse point closest to the wall where the probe can be positioned and the velocity probe head clears the port. It should be noted that the full extent of velocity decay may not be accounted for if measurements cannot be made at the 1-in. incremented wall effects traverse points closest to the wall.

    8.1.2.2 Calculate the following distances to within $\pm\frac{1}{4}$ in. (6.4 mm):

$$d_{rem_x} = d_{last} + \frac{\left(d_{b_x} - d_{last}\right)}{2} \qquad \text{Eq. 1}$$

    (a) d_{rem_x}

        Where:

            d_{b_x} = the distance from the test port wall to the interior edge of the Method 1 equal-area sector closest to that wall (Equation 2)

           d_{last} = the distance from the test port wall to the last one-inch measurement farthest from that wall as defined in Section 3.2. (If $d_{last} > d_{b_x}$, then substitute the greatest one-inch interval less than or equal to d_{b_x} in the preceding equation to calculate d_{rem_x}.)

$$d_{b_x} = \frac{L_x}{P_x} \qquad \text{Eq. 2}$$

Where:

L_x =   length of the duct or stack in the direction perpendicular to the test port wall (see Figure 1)

P_x =   number of traverse points at each test port as determined by Method 1

(b) d_{rem_y}

$$d_{rem_y} = d_{last} + \frac{\left(d_{b_y} - d_{last}\right)}{2} \qquad \text{Eq. 3}$$

Where:

d_{b_y} =   the distance from the wall perpendicular to the test port wall to the interior edge of the Method 1 equal-area sector closest to that wall (Equation 4)

d_{last} =   the distance from the test port wall to the last one-inch measurement farthest from that wall as defined in Section 3.2. (If $d_{last} > d_{b_y}$, then substitute the greatest one-inch interval less than or equal to d_{b_y} in the preceding equation to calculate d_{rem_y}.)

$$d_{b_y} = \frac{L_y}{P_y} \qquad \text{Eq. 4}$$

Where:

L_y =   length of the duct or stack in the direction parallel to the test port wall (see Figure 1)

P_y =   number of test ports required by Method 1 along a single wall

(c) d_{M1_y}

$$d_{M1_y} = \frac{d_{by}}{2} \qquad \text{Eq. 5}$$

8.1.3   Special considerations.   The following special considerations apply when the distance between traverse points is less than or equal to ½ in. (12.7 mm).

8.1.3.1   A wall effects traverse point and the Method 1 traverse point.   If the distance between a wall effects traverse point and the Method 1 traverse point is less than or equal to ½ in. (12.7 mm), taking measurements at both points is allowed but not required or recommended.

If measurements are taken at only one point, take the measurements at the point that is farther from the wall and use the velocity obtained at that point as the value for both points.

8.1.3.2 d_{rem} and d_{last}. If the distance between d_{last} and d_{rem_x}, d_{rem_y}, or d_{rem_c} is less than or equal to 1/2 in. (12.7 mm), taking measurements at d_{rem} is allowed but not required or recommended. If measurements are not taken at d_{rem}, the measured velocity value at d_{last} must be used as the value for both d_{last} and d_{rem}.

8.1.3.3 d_{rem_x} and d_{rem_y}. If the distance between the two d_{rem} points is less than or equal to ½ in. (12.7 mm), taking measurements at each of the affected points is allowed but not required or recommended. If measurements are not taken at each of the affected d_{rem} points, the measured velocity may be taken at one of them and substituted for the remaining point.

8.2 *Traverse Point Sampling Order and Probe Selection.* Determine the sampling order of the Method 1 and wall effects traverse points and select the appropriate probe(s) for the measurements, taking into account the following considerations.

8.2.1 To reduce the likelihood of velocity variation and its potential impact on the wall effect determinations, the following provisions of this method shall be met.

8.2.1.1 All wall effects traverse points specified in Section 8.1.2 shall be sampled without interruption.

8.2.1.2 During each run, the entire integrated Method 1 and wall effects traverse across all test ports shall be as short as practicable.

8.2.2 The same type of probe must be used to take measurements at all Method 1 and wall effects traverse points. However, different probes of the same type may be used at different ports (e.g., Type S probe 1 at port A, Type S probe 2 at port B) or at different traverse points accessed from a particular port (e.g., Type S probe 1 for Method 1 interior traverse points accessed from port A, Type S probe 2 for wall effects traverse points and the Method 1 exterior traverse point accessed from port A). The identification number of the probe used to obtain measurements at each traverse point must be recorded.

8.3 Reserved.

8.3.1 Reserved.

8.3.2 Reserved.

8.4 *Alternative Measurement Reduction Approaches (Optional).* The following alternatives may be used to reduce the number of measurements required to calculate WAF values. The velocities calculated using these alternative approaches will be used in conjunction with the procedures in Section 12 to determine WAF values.

8.4.1 In lieu of taking measurements at each point, Equation 9 may be used to calculate velocities for each one-inch interval and all other points (e.g., d_{remx}) that are less than 12 inches (30 cm) from the test port wall based on the velocity measured at the first available one-inch interval and the velocity measured 12 inches (30 cm) from the wall.

$$V_d = V_2 - (V_2 - V_1)\frac{\ln(d/12)}{\ln(y_1/12)} \quad \text{Eq. 9}$$

Where:

V_d = velocity at distance d from wall, ft/s (m/s)

V_1 = velocity at measured at the closest available one-inch interval from the wall, ft/s (m/s)

V_2 = velocity at measured at a distance of 12 inches (30 cm) from the wall, ft/s (m/s)

y_1 = distance of the closest available one-inch interval from the wall, in. (cm/2.54)

d = distance d from wall, in. (cm/2.54)

8.4.2 Duct or stack specific WAF default values may be determined in conjunction with the procedures of Section 12 using velocity values calculated in the following manner.

$$V_d = V_2\left[\frac{\ln\dfrac{d}{0.0024}+0.41(8.5)}{\ln\dfrac{y_2}{0.0024}+0.41(8.5)}\right] \quad \text{Eq. 10}$$

Where:

V_d = velocity at distance d from wall, ft/s (m/s)

V_2 = velocity measured at the first regular equal area traverse point, ft/s (m/s)

y_2 = reference distance determined in accordance with 8.4.2 a) or b), in. (cm/2.54)

d = distance d from wall, in. (cm/2.54)

a) Calculate the velocity at the near wall one-inch intervals (1 inch to 12 inches) using Equation 10. Use y_2 = distance from the wall of the first Method 1 equal area traverse point unless the distance is greater than 12 inches (30 cm) then use y_2 = 12 inches (30 cm).

b) Calculate the velocities at the d_{remx}, d_{remy}, and d_{M1y} locations using Equation 10. Use y_2 = distance from the wall of the first regular equal area traverse point. If the respective distance (d_{remx}, d_{remy}, or d_{M1y}) is greater than 12 inches (30 cm) but less than the distance from the wall of the first Method 1 equal area traverse point, substitute the velocity measured at the first Method 1 equal area traverse point for desired velocity.

9.0   *Quality Control*

9.1 *Verifying Traverse Point Distances.* In taking measurements at wall effects traverse points, it is very important for the probe impact pressure port to be positioned as close as practicable to the traverse point locations in the gas stream. For this reason, before beginning wall effects testing, it is important to calculate and record the traverse point positions that will be marked on each probe (or programmed for automated probes) for each port, taking into account the distance that each port nipple (or probe mounting flange for automated probes) extends out of the stack or duct and any extension of the port nipple (or mounting flange) into the gas stream. Ensure that the distance of each mark from the center of the probe impact pressure port agrees with the previously calculated traverse point positions to within ±¼ in. (6.4 mm).

9.2 *Probe Installation.* Properly sealing the port area is particularly important in taking measurements at wall effects traverse points. For testing involving manual probes, the area between the probe sheath and the port should be sealed with a tightly fitting flexible seal made of an appropriate material such as heavy cloth so that leakage is minimized. For automated probe systems, the probe assembly mounting flange area should be checked to verify that there is no leakage.

9.3 *Velocity Stability.* This method should be performed only when the average gas velocity in the stack or duct is relatively constant over the duration of the test. If the average gas velocity changes significantly during the course of a wall effects test, the test results should be discarded.

10.0   *Calibration*

The calibration coefficient(s) or curves obtained under Method 2, 2F, or 2G and used to perform the Method 1 traverse are applicable under this method.

11.0   *Analytical Procedure*

Sample collection and analysis are concurrent for this method (see Section 8).

12.0   *Data Analysis and Calculations*

The following calculations shall be performed to obtain a WAF.

12.1 *Nomenclature.* The following terms are listed in the order in which they appear in Equations 11 through 25.

v_x =   stack or duct gas point velocity value, unadjusted for wall effects, at Method 1 traverse point location (d_{M1}) for the exterior equal-area sectors adjacent to the test port wall, actual ft/sec (m/sec);

v_y =   stack or duct gas point velocity value, unadjusted for wall effects, at d_{M1_y} from the test port wall, actual ft/sec (m/sec);

v_c = stack or duct gas point velocity value, unadjusted for wall effects, at d_{MI} for corner test ports or at d_{MI} or d_{M1_y} (whichever distance is less) from for non-corner test ports, actual ft/sec (m/sec);

v_d = the measured stack gas velocity at distance d from the wall, actual ft/sec (m/sec); Note: $v_0 = 0$;

d = distance of a 1-in. incremented wall effects traverse point from the wall, for traverse points d_1 through d_{last}, in. (cm);

d = distance between one-inch intervals, 1 in., (2.5 cm);

d_{b_x} = distance from the test port wall to the interior edge of the Method 1 equal-area sector closest to that wall (see Equation 2);

d_{b_y} = distance from the wall perpendicular to the test port wall to the interior edge of the Method 1 equal-area sector closest to that wall (see Equation 4);

d_{last} = distance from the wall of the last 1-in. incremented wall effects traverse point, in. (cm);

v_{drem_x} = the measured stack gas velocity at distance d_{rem_x} from the test port wall, actual ft/sec (m/sec);

v_{drem_y} = the measured stack gas velocity at distance d_{rem_y} from the test port wall, actual ft/sec (m/sec);

v_{drem_c} = the measured stack gas velocity at a distance of d_{rem_x} for corner test ports or at a distance of d_{rem_x} if $d_{MI} \leq d_{M1_y}$ or d_{rem_y} if $d_{MI} > d_{M1_y}$ for non-corner test ports, actual ft/sec (m/sec);

v_{last} = the measured stack gas velocity at distance d_{last} from the wall, actual ft/sec (m/sec);

j = index test ports where near wall measurements are made;

n_x = total number of test ports where near wall measurements are made;

C_x = wall effects adjustment factor for a single traverse for all Method 1 non-corner, exterior equal-area sectors adjacent to the test port wall and the opposing test port wall, dimensionless;

C_y = wall effects adjustment factor for a single traverse for Method 1 non-corner, exterior equal-area sectors adjacent to the walls perpendicular to the test port wall, dimensionless;

C^*_c = wall effects adjustment factor for a single traverse for Method 1 corner equal-area sectors that excludes the impact of greater intense shear in the duct corners, dimensionless;

$C_{c_{adj}}$ = an adjustment factor applied to C^*_C to account for the impact of greater intense shear in the duct corners, calculated in accordance with Section 12.7, dimensionless;

C_c = wall effects adjustment factor for a single traverse for Method 1 corner equal-area sectors including the impact of greater intense shear in the duct corners, dimensionless;

i = index of Method 1 equal-area traverse points;

n = total number of traverse points in the Method 1 traverse;

$\hat{v}_x$ = stack or duct gas point velocity value, adjusted for wall effects, at Method 1 traverse point location (d_{M1}) for the exterior equal-area sectors adjacent to the test port wall, actual ft/sec (m/sec);

$\hat{v}_y$ = stack or duct gas point velocity value, adjusted for wall effects, at d_{M1_y} from the test port wall, actual ft/sec (m/sec);

$\hat{v}_c$ = stack or duct gas point velocity value, adjusted for wall effects, at d_{M1} or d_{M1_y} (whichever is less) from the test port wall, actual ft/sec (m/sec);

$\hat{v}_i$ = stack or duct gas point velocity value, adjusted for wall effects, at Method 1 equal-area sectors, actual ft/sec (m/sec);

v_{avg} = the average stack or duct gas velocity, unadjusted for wall effects, actual ft/sec (m/sec);

$\hat{v}_{avg}$ = the average stack or duct gas velocity, adjusted for wall effects, actual ft/sec (m/sec);

WAF = the overall wall effects adjustment factor derived from v_{avg} and $\hat{v}_{avg}$ for a single traverse, dimensionless;

$\overline{WAF}$ = the wall effects adjustment factor that is applied to the measurement location duct cross-sectional area value in order to determine wall effects-adjusted volumetric flow based on reference method or CEMS velocity measurements, dimensionless.

Q_{adj} = the total stack or duct gas volumetric flow rate, adjusted for wall effects, actual ft^3/sec (m^3/sec);

$Q_{adj_{std}}$ = the total stack or duct gas volumetric flow rate corrected to standard conditions, adjusted for wall effects, scf/sec (scm/sec);

A = duct or stack cross-sectional area at measurement location, ft^2

T_{avg} = average flue gas temperature, °R (°K) [°R = 460+°F (°K = 273+ °C)];

T_{std} = standard temperature, 528 °R (293 °K);

P_{avg} = average absolute flue gas pressure, in. Hg (mm Hg);

P_{std} = standard absolute pressure, 29.92 in. Hg (760 mm Hg);

12.2 Calculate the wall effects adjusted velocities for the Method 1 equal area sectors adjacent to the test port wall using the following equations.

12.2.1 Calculate the wall effects adjusted velocity, $\hat{v}_x$, for each of the Method 1 equal-area sectors adjacent to the test port wall using Equation 11. If $d_{last} > d_{b_x}$, substitute the greatest one-inch interval less than d_{b_x} for d_{last}.

$$\hat{v}_x = \frac{\left[\sum_{d=1}^{d_{last}-1} (v_d)d + \frac{v_{last}}{2}d + v_{dremx}\left(d_{b_x} - d_{last}\right) \right]}{d_{b_x}} \quad \text{Eq. 11}$$

12.2.2 Calculate the wall effects adjusted velocity, $\hat{v}_y$, for each of the Method 1 equal-area sectors adjacent to the test port wall using Equation 12. If $d_{last} > d_{b_y}$, substitute the greatest one-inch interval less than d_{b_y} for d_{last}.

$$\hat{v}_y = \frac{\left[\sum_{d=1}^{d_{last}-1} v_d \, d + \frac{v_{last}}{2} d + v_{dremy}\left(d_{b_y} - d_{last}\right)\right]}{d_{b_y}} \quad \text{Eq. 12}$$

12.2.3 Calculate the wall effects adjusted velocity, $\hat{v}_c$, for each of the Method 1 equal-area sectors adjacent to the test port wall using Equation 13. If $d_{last} > d_{b_x}$ or $d_{last} > d_{b_y}$, substitute the greatest one-inch interval less than d_{b_x} or d_{b_y} (whichever is less) for d_{last}.

$$\hat{v}_c = \frac{\sum_{d=1}^{d_{last}} \left[\left(\frac{v_{d-1}+v_d}{2}\right)\left(d_{b_x} + d_{b_y} - 2d + 1\right)\right] d + v_{drem_c}\left(d_{b_x} - d_{last}\right)\left(d_{b_y} - d_{last}\right)}{d_{b_x} d_{b_y}} \quad \text{Eq. 13}$$

12.2.4 Reserved.
12.2.4.1 Reserved. (Equation 14 Reserved.)
12.2.4.2 Reserved. (Equation 15 Reserved.)

12.3 Calculate the velocity correction factors for the Method 1 equal area sectors adjacent to the test port wall using the following equations. If any of the test ports are located 12 or less inches from an adjacent wall, then reduce n_x by the number of those ports and substitute that value for n_x in the following equations.

12.3.1 Calculate the wall effects correction factor, C_x, for Method 1 non-corner equal-area sectors adjacent to the test port wall and the opposing test port wall using Equation 16.

$$C_x = \frac{\sum_{j=1}^{n_x} \left(\frac{\hat{v}_x}{v_x}\right)_j}{n_x} \quad \text{Eq. 16}$$

12.3.2 Calculate the wall effects correction factor, C_y, for Method 1 non-corner equal-area sectors adjacent to the walls perpendicular to the test port wall using Equation 17.

$$C_y = \frac{\sum_{j=1}^{n_x} \left(\frac{\hat{v}_y}{v_y}\right)_j}{n_x} \quad \text{Eq. 17}$$

12.3.3 Reserved. (Equation 18 Reserved.)

12.3.4 Calculate the wall effects correction factor, C^*_c, for all Method 1 corner equal-area sectors using Equation 19.

$$C^*_c = \frac{\sum\limits_{j=1}^{n_x} \left(\frac{\hat{v}_c}{v_c}\right)_j}{n_x} \quad \text{Eq. 19}$$

12.3.5 Reserved.

12.4 Calculate the velocity in each Method 1 equal-area sector, $\hat{v}_i$, adjusted for wall effects, using Equation 21.

$$\hat{v}_i = v_i \times C_i \quad \text{Eq. 21}$$

Where:

C_i is the appropriate correction factor for the given Method 1 equal-area sector:

C_i = 1 for Method 1 interior equal-area sectors

C_i = C_x for Method 1 non-corner, exterior equal-area sectors adjacent to the test port wall or the opposing test port wall

C_i = C_y for Method 1 non-corner, exterior equal-area sectors adjacent to the walls perpendicular to the test port wall

C_i = C_c for Method 1 corner equal-area sectors. $C_C = C^*_C \times C_{c_{adj}}$ (See Section 12.7)

12.5 Calculate the wall adjustment factor, *WAF*, using Equations 22 through 24.

12.5.1 Calculate the average stack or duct gas velocity that does not account for velocity decay near the wall (v_{avg}) using Equation 22.

$$v_{avg} = \frac{\sum\limits_{i=1}^{n} v_i}{n} \quad \text{Eq. 22}$$

12.5.2 Calculate the average stack or duct gas velocity, adjusted for wall effects, $\hat{v}_{avg}$, using Equation 23.

$$\hat{v}_{avg} = \frac{\sum\limits_{i=1}^{n} \hat{v}_i}{n} \quad \text{Eq. 23}$$

12.5.3 Calculate the wall effects adjustment factor, *WAF*, using Equation 24.

$$WAF = \frac{\hat{v}_{avg}}{v_{avg}} \quad \text{Eq. 24}$$

12.6 *Applying a Wall Effects Adjustment Factor.* A calculated wall effects adjustment factor may be used to adjust the average flue gas volumetric flow obtained using Methods 2, 2F, or 2G or CEMS measurements to take into account velocity decay near the wall of rectangular stacks or ducts using Equation 25a or 25b.

$$Q_{adj} = v_{avg} \left(\overline{WAF} \times A \right) \quad \text{Eq. 25a}$$

$$Q_{adj\,std} = v_{avg} \frac{T_{std}}{T_{avg}} \frac{P_{avg}}{P_{std}} \left(\overline{WAF} \times A \right) \quad \text{Eq. 25b}$$

The wall effects adjustment factor, $\overline{WAF}$, shown in Equation 25a and 25b, must be the arithmetic average of WAF values obtained during at least three wall effect test runs unless a stack or duct specific WAF default factor is calculated in accordance with Section 8.4.2. A $\overline{WAF}$ can only be applied when calculating volumetric flows based on velocity data from RATAs consisting of the same number of Method 1 traverse points used to determine the $\overline{WAF}$ or from a CEMS for which such a RATA has been conducted. The $\overline{WAF}$ must be reassessed whenever the stack or ductwork is altered such that the flow profile is significantly changed.

12.7 *Corner Correction.* A default value of $C_{c_{adj}} = 0.995$ may be used for any duct to account for the more intense viscous shear in the corner regions. Alternatively, calculate a duct specific $C_{c_{adj}}$ using Equation 26:

$$C_{c_{adj}} = 1 - 0.25 \left[1 - \left(\frac{\log \dfrac{eD_{eff}}{3.7}}{\log \dfrac{eD_h}{3.7}} \right)^2 \right] \quad \text{Eq. 26}$$

Where:

D_h = hydraulic diameter, ft (m); 4 × cross-sectional area / perimeter
D_{eff} = effective diameter including corner impact; $D_{eff} = [64/(fRe)]D_h$
ε = average duct surface roughness, ft (m)

Calculate D_{eff}, using the value for friction constant, fRe, from the Table 1, interpolating as needed. The parameter b/a is the duct aspect ratio, where b represents the smaller of the two stack or duct dimensions.

Table 1. Friction Constants for Rectangular Ducts

b/a	f Re	b/a	f Re
0.00	96.00	0.25	72.93
0.05	89.91	0.40	65.47
0.10	84.68	0.50	62.19
0.125	82.34	0.75	57.89
0.167	78.81	1.00	56.91

Calculate the average stack or duct surface roughness, ε, based on the surface roughness values calculated for each test port location using the Equation 27:

$$e = e^{8.5(0.41)}\left(\frac{y_1}{12}\right)^{\frac{V_2}{V_2-V_1}} \quad \text{Eq. 27}$$

Where:

V_1 = velocity measured at the closest available one-inch interval from the wall, ft/s (m/s)

V_2 = velocity measured at a distance of 12 inches (30 cm) from the wall, ft/s (m/s)

y_1 = distance of the closest available one-inch interval from the wall, in. (cm $\times$ 0.12)

13.0   *Method Performance* [Reserved]

14.0   *Pollution Prevention* [Reserved]

15.0   *Waste Management* [Reserved]

16.0   *Reporting*

16.1 *Field Test Reports.* Field test reports shall be submitted to the Agency according to the applicable regulatory requirements. When this method is performed in conjunction with Method 2, 2F, or 2G to derive a wall effects adjustment factor, a single consolidated field test report should be prepared. At a minimum, the consolidated field test report should contain (1) all of the general information, and data for Method 1 points, specified in Section 16.0 of Method 2F (when this method is used in conjunction with Method 2F) or Section 16.0 of Method 2G (when this method is used in conjunction with Method 2 or 2G) and (2) the additional general information, and data for Method 1 points and wall effects points, specified in this section (some of which are included in Section 16.0 of Methods 2F and 2G and are repeated in this section to ensure complete reporting for wall effects testing).

16.2 *Data for each run.* The following run values should also be included in the field test report.

(a) Average velocity for run, accounting for wall effects, $\hat{v}_{avg}$.

(b) Wall effects adjustment factor derived from a test run, WAF.

16.3 *Quality Assurance and Control.* Quality assurance and control procedures, specifically tailored to wall effects testing, should be described.

16.4 *Reporting a Default Wall Effects Adjustment Factor.* [Reserved]

17.0 References.

Impact of Viscous Shear Wall Effects on Flow Measurements in Rectangular Ducts, EPRI, Palo Alto, CA. 10076649.

Norfleet, Stephen K. *Impact of Wall Effects on Flue Gas Velocities in Rectangular Ducts and Recommended Revisions to EPA Reference Method 2H*, 2000 EPRI CEMS Users Group Meeting, San Antonio, Texas, May 2000.

Norfleet, Stephen K. *An Evaluation of Wall Effects on Stack Flow Velocities and Related Overestimation Bias in EPA's Stack Flow Reference Methods*, 1998 EPRI CEM Users Group Meeting, New Orleans, Louisiana, May 1998.

White, Frank M. *Fluid Mechanics*, 2nd ed., McGraw-Hill, New York. 1986.

EPA Flow Reference Method Testing and Analysis: Findings Report, US EPA, Acid Rain Division, EPA/430-R-99-009a, May 1999.

40 CFR Part 60, Appendix A, "Method 1-Sample and Velocity Traverses for Stationary Sources."

40 CFR Part 60, Appendix A, "Method 2-Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)."

40 CFR Part 60, Appendix A, "Method 2F-Determination of Stack Gas Velocity and Volumetric Flow Rate with Three-Dimensional Probes."

40 CFR Part 60, Appendix A, "Method 2G-Determination of Stack Gas Velocity and Volumetric Flow Rate with Two-Dimensional Probes."
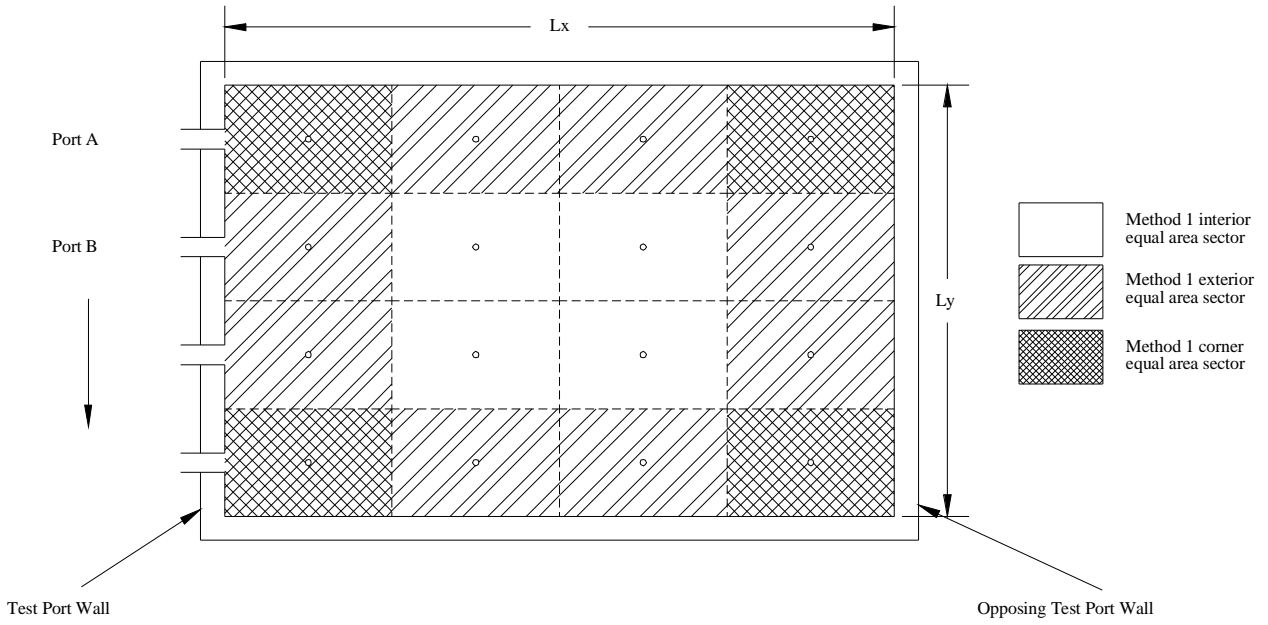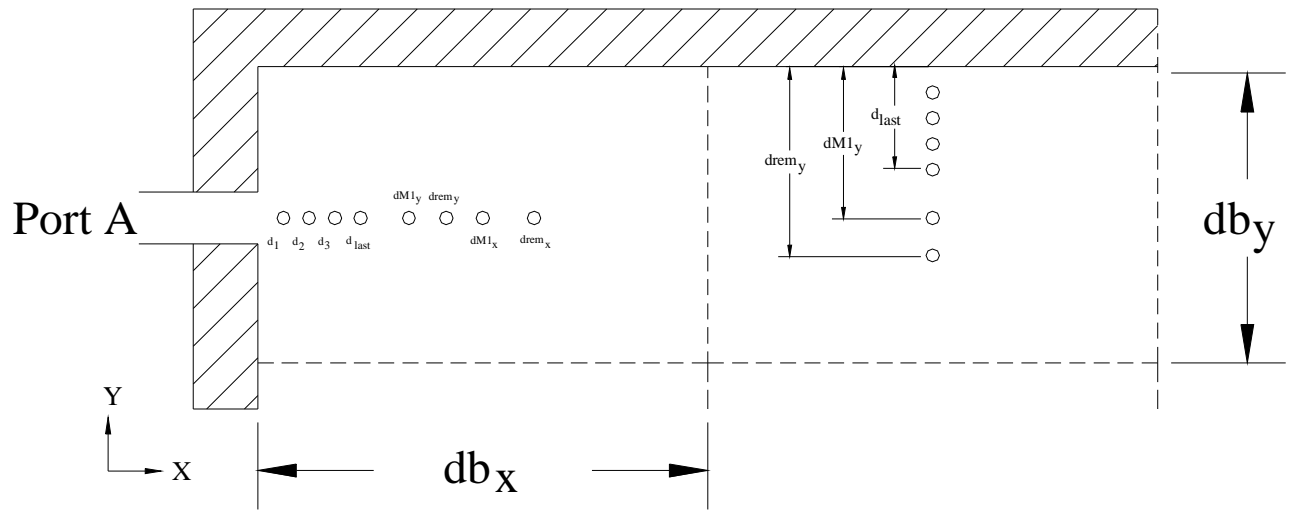
Figure 1. Rectangular duct sectors

Figure 2. Wall effects traverse points

Figure 3. Reserved.