

## **An ORS-Based, Mass-Balance Method for Estimating Air Emissions from AFO Area Sources**

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### **ABSTRACT**

This paper presents an ORS-based, mass-balance method for the estimation of volatile compound emissions from complex, ground-level fugitive sources (i.e., area sources), such as AFO lagoons and waste-disposal areas. The method utilizes open-path spectroscopy to generate path-integrated, contaminant concentration data in the cross-plume dimension (“whole-plume” approach), and offers a rapid and inexpensive means of reliably assessing emissions from such sources. Referred to as the “modified area-source technique,” the method was developed in the early 1990s by the USEPA. Parameterization of vertical dispersion between the source and the downwind measurements obviates the need for emissions or meteorological profiling in the vertical dimension. The analysis reduces to one of conservation of mass, as the extent of the pollutant’s lateral and vertical dispersion is taken into account.

The simplicity of this approach enables annual emission rates to be made by measuring “snapshot” emissions under a representative range of process scenarios and meteorological (wind and temperature) conditions. Finally, a straightforward means of extending the emissions estimates to odor-causing compounds not detectable by open-path spectroscopy is described, and a case-study example involving a similar source type is presented.

### **INTRODUCTION**

On January 31, 2005, the USEPA provided the opportunity for companies engaged in animal feeding operations (AFOs) to sign a voluntary consent agreement (Agreement) which, in exchange for “safe harbor” provisions with respect to enforcement proceedings resulting from potentially injurious air emissions, would enable participants to “pool their resources to lower the cost of measuring emissions and ensure that they comply with all applicable environmental regulations in the shortest amount of time.”<sup>1</sup>

The Agreement requires each participating company, among other things, to “be responsible for the payment of funds towards a two-year national air emissions monitoring study that will lead to the development of Emissions-Estimating Methodologies that will help animal feeding operations determine and comply with their regulatory responsibilities under the Clean Air Act, CERCLA and EPCRA.”<sup>1</sup> Several AFO emission-source types exist, but the most challenging is the area source, which includes wastewater lagoons and open manure piles.

Two optical remote sensing (ORS) approaches for assessing AFO area sources are identified in the Agreement: “Eulerian Gaussian” and “Lagrangian Stochastic.” An advantage shared by all ORS methods is the generation of a path-integrated concentration. To the extent that this optical path can cover the entire contaminant plume from an area, only two additional pieces of information are needed to develop a flux estimate: the plume configuration in the vertical, and an estimate of a representative wind speed. When an ORS-measurable tracer is used, however, the need to measure these two parameters is reduced to the much simpler task of estimating the extent to which the tracer release matches the pollutant emissions. Presented first is a discussion of the monitoring approaches mentioned in the Agreement, followed by a method, developed by USEPA in the early 1990s, which is shown to be simpler and less expensive than either approach, and which provides emissions data of a higher quality in a fraction of the time.

## **AREA-SOURCE MONITORING APPROACHES IDENTIFIED IN THE AGREEMENT**

There are few specifics in the Agreement concerning the Eulerian Gaussian and Lagrangian Stochastic approaches. Technical discussion is limited to five paragraphs which provide more logistical detail than necessary (e.g., “A team of two persons with two scanning FTIR systems, two single-path UV-DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.”), yet fail to rise to the level of completeness of a USEPA method document with error analysis and expected outcomes. No further details on either approach are provided in the Agreement, and no references are cited. An extensive Internet search yielded little additional information except that the Computerized Tomography analysis technique included as a component of the Eulerian Gaussian method is the subject of a US patent co-owned by an employee of USEPA’s in-house contractor, ARCADIS.<sup>2</sup> Basically, the vertical profile of the plume is estimated from ORS measurements in a vertical plane, even though much of the plume may reside above the measurements, and the wind speeds in the vertical (normal to the measurement plane) are likewise estimated using several anemometers.

The technical information on the two Agreement approaches is insufficient to perform an in-depth analysis. The authors do believe, however, that there will be circumstances when neither approach is able to generate data of the precision and accuracy necessary to achieve the program objectives. USEPA demonstrated 15 years ago that vertical profiling of contaminant or meteorological data is not necessary in order to assess emissions from non-buoyant, ground-level area sources.<sup>3</sup> In fact, for such sources, the overall data quality is actually *maximized* with only ground-level pollutant measurements and coincident meteorology, provided there is proper treatment of vertical dispersion via the controlled release and measurement of tracer gases (discussed below). If the vertical dispersion in the microscale region is properly parameterized, the arduous task of determining vertical pollutant or wind profiles becomes unnecessary. The problem reduces to one of conservation of mass, as the extent of the pollutant’s lateral and vertical dispersion is taken into account. Referred to as the area-source technique, this approach was developed by the USEPA’s National Environmental Response Team (ERT) in the early 1990s and has been extensively documented.<sup>4-12</sup>

Continuous emissions measurements have been made from a landfill in Sweden using this technique for several years.<sup>13</sup> The reason that tracer-based techniques improve accuracy is that in the simplest approximation, in which the tracer release exactly mimics the location of the pollutant flux, no other information is needed except the path-integrated readings for the pollutant and the tracer, coupled with the known tracer release rate. In practice, this is never the case, and meteorological measurements and calculations are needed. However, the fact is that a source flux of pollutant is derived relatively directly from a known flux of one or more tracers.

## **MODIFIED AREA-SOURCE TECHNIQUE**

### **Overview**

Several ORS-based, volume-source emissions-estimation techniques exist, most notably the Swedish solar occultation flux (SOF) method,<sup>14</sup> commercially available at “[www.fluxsense.se](http://www.fluxsense.se)”. It might be most efficient to initially use a technique such as SOF in a “screening” approach to estimate the total emissions from a given AFO. This technique could then be used to rank individual sources for more refined investigation. In cases where the major sources are area sources such as lagoons, use of the area-source technique would then be indicated.

The area-source technique involves identification of a source attribution based on a series of near-ground, downwind ORS-based measurements, and the subsequent back-calculation of emission rates based on Gaussian dispersion relationships inherent in most USEPA Guideline models. It is applicable to all area-type sources, i.e., homogeneous sources (uniformly emitting) and non-homogeneous sources (having “hot spots”).

“Hot spots” are accommodated to the degree that the *relative source strength* of the emissions subareas can be ascertained. Onsite meteorological requirements are limited to wind speed, wind direction, and parameters relating to atmospheric dispersion. Each “monitoring event” is typically 10 or 15 minutes.

Modification of this method (i.e., modified area-source technique) involves the use of tracer gases to develop a vertical dispersion (sigma-z) curve applicable to each monitoring event. These site-specific sigma-z curves are then substituted into the dispersion model to improve the accuracy of the back-calculated emissions. The modified area-source technique can also be used to reliably estimate emissions of volatile compounds which are present below the ORS instrument’s minimum detection level (MDL). Because of the simplicity of the method and the relative ease of its implementation, an annual emission rate (e.g., tons per year) can be developed by measuring “snapshot” emissions under reasonable ranges of processes and wind and temperature conditions.

### **Method**

Following is the general approach for the area-source technique (unmodified), treatment of hot spots, treatment of compounds present below the instrument’s MDL, modified treatment of vertical dispersion, and case-study examples of emission-rate and hot-spot assessments and derivation of sigma-z curves.

### ***General Approach***

The area-source technique (unmodified) is basically the same for AFO lagoons and manure piles. The approach is straightforward and is presented in the following three steps:

#### 1. Identify Source Attribution

A series of 10-minute-averaged, ground-level ORS measurements (within the lowest 2 meters) are made immediately downwind of the lagoon (or manure pile). Wind speed, wind direction, and atmospheric stability class are averaged over each monitoring event. All meteorological measurements are made using an appropriately configured, portable 3-meter meteorological tower at a location judged representative of the microscale region between the source and the downwind measurement path. Ideally, the ORS crosswind measurement path should be of sufficient length to fully encompass the plume.

#### 2. Predict Relative Path-Integrated Concentration Along Measurement Path

An appropriate dispersion model (e.g., ISCST<sup>15</sup>) is configured to predict the relative path-integrated concentration along the downwind measurement path defined in Step 1. This is most easily accomplished by: (a) predicting the point concentration ( $\text{mg}/\text{m}^3$ ) at every meter along the measurement path based on a unity emission rate (e.g.,  $1 \text{ mg}/\text{s}\cdot\text{m}^2$ ) and actual meteorology and source configuration; (b) determining the arithmetic average of the predicted point concentrations ( $\text{mg}/\text{m}^3$ ); and (c) multiplying the average point concentration by the downwind pathlength (m).

For a given downwind, path-integrated concentration, the estimated emission rate is dependent upon how much mass has dispersed in the vertical, above the source, prior to reaching the instrument. In Gaussian theory, compound loss in the vertical can be estimated through knowledge of the vertical dispersion ( $\sigma_z$ ) coefficient, which may be thought of as the height one would have to go above a plume centerline before the concentration is reduced by a factor of  $1/e$ , or about 36.8%.  $\sigma_z$  increases with increasing downwind distance from the source. Because its measurement is not trivial,  $\sigma_z$  is generally approximated based on consideration of atmospheric stability class. For dispersion modeling purposes, Pasquill-Gifford (P-G) stability classes A through F are typically identified, in which Class A is the least stable (large  $\sigma_z$  values) and Class F is the most stable (small  $\sigma_z$  values). For each stability class, a unique formula is used to assign a  $\sigma_z$  value as a function of downwind distance.<sup>15</sup>

Hot spots are represented in the unity modeling by assigning relative emission factors to each source subarea (explained below). Several methods for obtaining the relative emissions-subarea source strengths are provided, as well as a simple means of bounding the emissions without such information.

#### 3. Scale Unity Modeling Results to Estimate Emission Rate

For each target compound, the actual emission rate,  $Q_A$ , is estimated in accordance with the following ratio:

$$C_M / Q_A = C_P / Q_U \quad (\text{Equation 1})$$

where, for each monitoring event:

$C_M$	=	measured path-integrated concentration ( $\text{mg}/\text{m}^2$ )
$Q_A$	=	actual emission rate ( $\text{mg}/\text{s}\cdot\text{m}^2$ )
$C_P$	=	predicted relative path-integrated concentration ( $\text{mg}/\text{m}^2$ )
$Q_U$	=	unity-based emission rate ( $\text{mg}/\text{s}\cdot\text{m}^2$ )

### ***Treatment of Hot Spots***

Hot spots refer to discrete subareas (within a larger area source) from which a compound's emissions are a relative maximum. By definition, all heterogeneous sources contain hot spots.

As mentioned in Step 2 above, a hot spot is represented in the unity modeling by assigning a relative emission factor to each source subarea. For example, if the emissions from a hot-spot subarea is shown to be 4 times higher than the remaining area, that subarea is assigned an emission rate of 4 times unity for the unity modeling. The total unity-based emission rate ( $\text{mg}/\text{s}$ ) is derived by adding the "weighted" contribution of each source subarea, as determined by the product of its unity-based emission factor ( $\text{mg}/\text{s}\cdot\text{m}^2$ ) and its area ( $\text{m}^2$ ). This is illustrated in a case-study example later.

There are several methods for obtaining hot-spot emission rates. One way is to grid the lagoon and collect measurements at a constant height above the surface under calm (or nearly calm) conditions. The lagoon is then divided in several subareas based on the magnitude and distribution of near-surface measurements. Point concentrations are averaged within each subarea, and the unity-based, hot-spot emission rate for a given subarea is assigned simply by dividing that subarea's average concentration by the average concentration of the lowest-emitting subarea (i.e., hot spots are defined in terms of multiples of the lowest-emitting subarea).

Another method for apportioning hot-spot emissions involves use of computed radial tomography applied in the horizontal plane.<sup>16</sup> This can be an especially attractive approach owing to the difficulty in characterizing the point concentrations across large lagoons.

Finally, hot spots (in air) can be estimated according to the aqueous concentration distribution across the lagoon surface together with Henry's Law constant information, water solubility, and water temperature.<sup>3</sup>

In the absence of hot-spot apportionment data, an upper bound upon the emissions can be set by assuming that all of the contaminants are being uniformly emitted from the upwind-most portion of the lagoon (e.g., half, third, or quarter, depending on the knowledge of aqueous contaminant distribution). Conversely, a lower bound can be set by assuming all of the contaminants are being uniformly emitted from the downwind-most portion. The unmodified approach not only depends upon proper choice of the six discrete stability classes, but also on the assumption of a Gaussian profile with altitude.

### ***Treatment of Compounds Present Below the MDL***

Typically, only a few of the target compounds will be present at concentrations above the instrument's MDL; other compounds, while present, will not be of sufficient concentration to be detected. A simple way to extend the area-source technique to these compounds is to approximate the path-integrated concentration by walking a flow-controlled Summa canister back and forth along the ORS path during the measurement event. This yields a path-averaged concentration which, when multiplied by the pathlength (one way), provides a representative path-integrated concentration. The proportion of relative compound abundance in the canister (usually determined by GC/MS analysis) is then applied to the ORS data in order to assign a path-integrated concentration to those compounds present below the instrument's MDL. In this manner, an ORS-detected compound is used as a surrogate for the nondetected compounds. Recent advances in Summa canister design have enabled sub-ppb MDLs to be achieved for most compounds of concern.<sup>17</sup>

### ***Modified Treatment of Vertical Dispersion***

Limiting the sigma-z coefficient to one of six discrete values for a given downwind distance represents a simplification (which introduces error) in the emissions back-calculation process, as vertical dispersion is actually a continuous function. The error introduced by assuming a step-type function is eliminated through the development of site-specific vertical dispersion curves unique to each measurement event. This is accomplished by releasing dual tracer gases (e.g., carbon tetrafluoride, CF<sub>4</sub> and sulfur hexafluoride, SF<sub>6</sub>) at known, constant flow rates from two upwind distances, and the subsequent creation of a best-fit, second-degree polynomial to describe sigma-z over the downwind region of interest. These curves, each of which provides accurate simulation of the plume's vertical dispersion over the corresponding 10-minute period, are substituted into the model to ensure back-calculation of accurate emission rates. This refined treatment of vertical dispersion makes use of the crosswind-integrated form of Turner's general Gaussian equation for ground-level concentration downwind of a continuously emitting, ground-level point source:<sup>18</sup>

$$\sigma_z = (2\pi)^{1/2} Q (\pi C u)^{-1} \quad \text{(Equation 2)}$$

where:

$\sigma_z$	=	vertical dispersion coefficient at the particular downwind distance (m)
$Q$	=	uniform tracer-gas emission rate (mg/s)
$C$	=	ground-level, crosswind-integrated tracer-gas concentration (mg/m <sup>2</sup> )
$u$	=	mean wind speed (m/s)

In this modified case, even though Gaussian theory is used, the tracer data in large part accounts for any error introduced by the lack of Gaussian dispersion.

### ***Case-Study Examples***

Following are case-study examples of emission-rate and hot-spot assessments and derivation of site-specific sigma-z curves. These examples are part of a 9-week, facility-wide emissions

characterization study performed during the summer of 2001 to facilitate identification of odor-control needs as part of a New York City municipal wastewater treatment plant (WTP) upgrade.<sup>19</sup> The contaminant of concern was hydrogen sulfide (H<sub>2</sub>S), path-integrated concentrations of which were approximated via extensive cross-plume sampling using a hand-held Jerome meter.

A total of 77 monitoring events (modified area-source technique) were carried out for the preliminary settling tanks to support identification of subtle process variations in event-to-event emissions. Both hot-spot apportionment and refined treatment of vertical dispersion were performed during each event. All data shown in the following case-study examples were collected sequentially on August 6, 2001.

### Emission-Rate and Hot-Spot Assessments

**Table 1** presents the final H<sub>2</sub>S emission-rate determinations for the preliminary settling tanks (using the event-specific, sigma-z curves which are derived below).

**Table 1.** Final H<sub>2</sub>S Emission-Rate Determinations for the Preliminary Settling Tanks

Arbitr. Event	ISCST3 Unity Analysis		Meteorology				Measured Source Attrib. (g/m <sup>2</sup> )	Actual Emission Rate (g/s)		
	Emission Rate (g/s)	Predicted Source Attrib. (g/m <sup>2</sup> )	10m WD (°)	1m WS (m/s)	P-G Stab. Class	Temp. (°K)		Quiescent Areas	Turbulent Areas	Total
1	2.04	0.251	181	2.9	E-F	303	0.0136	0.0183	0.0925	0.111
2	2.04	0.236	199	2.4	E-F	303	0.0132	0.0188	0.0950	0.114
3	2.04	0.235	210	2.2	E-F	303	0.0128	0.0183	0.0925	0.111
4	2.04	0.221	206	2.2	E-F	303	0.00759	0.0115	0.0584	0.0701
5	2.04	0.222	184	2.6	E-F	303	0.0143	0.0216	0.109	0.131
6	2.04	0.221	187	2.9	E-F	303	0.0114	0.0173	0.0875	0.105
7	2.04	0.204	184	2.5	E-F	303	0.0109	0.0180	0.0908	0.109
8	2.04	0.160	181	2.2	D	303	0.00669	0.0140	0.0711	0.0853

The *ISCST3* unity analysis emission rate was derived by considering a unity emission rate of 0.0001 g/m<sup>2</sup>-s over the quiescent areas (calculated to be 3,362 m<sup>2</sup>) together with a “hot-spot-adjusted” unity emission rate of 0.0098 g/s-m<sup>2</sup> over the turbulent areas (calculated to be 173 m<sup>2</sup>), which yielded a total unity-based emission rate of 2.04 g/s (0.336 g/s + 1.70 g/s). The “hot-spot-adjusted” unity emission rate of 0.0098 g/s-m<sup>2</sup> was derived based on results of a comprehensive hot-spot measurement program, in which the average H<sub>2</sub>S concentration immediately above the weir (turbulent) areas (17 locations) was 98 times greater than the average concentration over the remaining (quiescent) areas (10 locations).

The *predicted unity-based source attribution* was obtained by running the ISCST3 Model with the above source strengths and configurations for the meteorology observed, and with refined treatment of vertical dispersion (discussed below). This attribution may be thought of as the resultant path-integrated concentration based on a source emissions of unity for the quiescent areas and 98 times unity for the turbulent (weir) areas.

The *total actual emission rate* (last column) was obtained using Equation 1 solved for  $Q_A$ .

Finally, the apportionment of the *quiescent areas* and the *turbulent areas* to the total emissions was derived by adjusting the total emissions in proportion to the unity-based emission rates for these areas. For example, for (arbitrary) Event 1, the actual emission rate for the quiescent areas is  $(0.336 \text{ g/s} \div 2.04 \text{ g/s}) \times 0.111 \text{ g/s} = 0.0183 \text{ g/s}$ . Similarly, the actual emission rate for the turbulent areas is  $(1.70 \text{ g/s} \div 2.04 \text{ g/s}) \times 0.111 \text{ g/s} = 0.0925 \text{ g/s}$ .

### Derivation of Sigma-z Curves

A second-order sigma-z curve, unique to each of the 77 monitoring events, was developed and substituted into the ISCST Model to support the above  $H_2S$  emission assessments. Results of these sigma-z curve derivations are shown in order to illustrate the refined (modified) treatment of vertical dispersion.

The approach involved release of  $CF_4$  and  $SF_6$  at controlled flow rates (0.038 g/s and 0.109 g/s, respectively), each from an elevation of 1 meter, from locations 22.3 meters and 46.9 meters, respectively, upwind of the ORS (in this case FTIR) beam path. These tracer gases were monitored as path-integrated concentrations, immediately downwind of the source.

In order to accommodate winds from a southerly quadrant, the transmitter and retroreflector were positioned in an east-west orientation, about 1 meter north of the source's northern boundary during all measurements. The beam pathlength (one-way) was 81.5 meters, and the beam was positioned at a height about 1 meter off the ground.

**Table 2** and **Table 3** present sigma-z calculations, based on the measurement of  $CF_4$  and  $SF_6$ , respectively, to support the eight case-study monitoring events for the preliminary settling tanks.

*Initial sigma-z* ( $\sigma_z$ ) values are presented for each monitoring event (15 minutes for this study) based on the crosswind-integrated form of Turner's equation (Equation 2) and assuming that the wind was perpendicular to the beam path (i.e., from the south or  $180^\circ$ ). Based on the departure of mean (actual) 10-meter wind direction from normal, adjustments were made to the distances downwind of the tracers at which each sigma-z value applies. This was accomplished by dividing the normal downwind distances of the tracers (22.3 and 46.9 meters) by the cosine of the absolute value of the difference between the mean wind direction and  $180^\circ$ .

**Table 2.** Preliminary Settling Tank Sigma-z Calculations Based on Carbon Tetrafluoride Data

Arbitr. Event	Meteorology			CF <sub>4</sub> Conc. (g/m <sup>2</sup> )	Q (g/s)	Initial $\sigma_z$ @ 22.3m (m)	Adjusted Downwind Distance (m)	Plume-Capture Adjustment		
	10m WD (°)	10m $\sigma_\theta$ (°)	1m WS (m/s)					Plume Capture (%)	Adjusted CF <sub>4</sub> Conc. (g/m <sup>2</sup> )	Final $\sigma_z$ (m)
1	181	13.7	2.9	0.00767	0.0380	1.36	22.3	100	0.00767	1.36
2	199	17.3	2.4	0.00748	0.0380	1.68	23.6	100	0.00748	1.68
3	210	14.1	2.2	0.00690	0.0380	1.97	25.8	100	0.00690	1.97
4	206	17.0	2.2	0.00691	0.0380	2.00	24.8	100	0.00691	2.00
5	184	8.0	2.6	0.00667	0.0380	1.75	22.4	100	0.00667	1.75
6	187	8.3	2.9	0.00657	0.0380	1.61	22.5	100	0.00657	1.61
7	184	9.2	2.5	0.00550	0.0380	2.20	22.4	100	0.00550	2.20
8	181	9.8	2.2	0.00485	0.0380	2.85	22.3	100	0.00485	2.85

**Table 3.** Preliminary Settling Tank Sigma-z Calculations Based on Sulfur Hexafluoride Data

Arbitr. Event	Meteorology			SF <sub>6</sub> Conc. (g/m <sup>2</sup> )	Q (g/s)	Initial $\sigma_z$ @ 46.9m (m)	Adjusted Downwind Distance (m)	Plume-Capture Adjustment		
	10m WD (°)	10m $\sigma_\theta$ (°)	1m WS (m/s)					Plume Capture (%)	Adjusted SF <sub>6</sub> Conc. (g/m <sup>2</sup> )	Final $\sigma_z$ (m)
1	181	13.7	2.9	0.0166	0.1087	1.80	46.9	100	0.0166	1.80
2	199	17.3	2.4	0.0146	0.1087	2.46	49.6	100	0.0146	2.46
3	210	14.1	2.2	0.0150	0.1087	2.59	54.2	97.1	0.0154	2.52
4	206	17.0	2.2	0.0134	0.1087	2.95	52.2	99.5	0.0135	2.94
5	184	8.0	2.6	0.0127	0.1087	2.64	47.0	100	0.0127	2.64
6	187	8.3	2.9	0.0142	0.1087	2.14	47.3	100	0.0142	2.14
7	184	9.2	2.5	0.0117	0.1087	2.96	47.0	100	0.0117	2.96
8	181	9.8	2.2	0.00763	0.1087	5.19	46.9	100	0.00763	5.19

Tracer-gas *plume capture* was assessed by modeling selected events using actual meteorology. Plume-capture adjustments were made, as required, to account for the fact that the FTIR beam was not always long enough to capture the outer edges of the tracer-gas plumes owing to the departure from normal of the mean wind direction and to horizontal dispersion. Incomplete plume capture occurred most often for SF<sub>6</sub>, as this was the tracer released furthest upwind.

*Plume-capture assessment* required appropriate treatment of atmospheric stability (i.e., horizontal and vertical dispersion) in the model. For CF<sub>4</sub>, this involved use of the horizontal and vertical dispersion coefficients based on the P-G stability class as determined for each event using the sigma-theta method.<sup>20</sup> For SF<sub>6</sub>, this also involved use of the horizontal and vertical dispersion coefficients based on the P-G stability class; however, in this case, the P-G stability class was assigned to each event using the CF<sub>4</sub>-based sigma-z data (vs. the sigma-theta method), as it utilized measured vertical dispersion coefficients across the source. The model was then configured to predict concentrations at every meter along the beam path (and along appropriate beam-path extensions), and plume-capture estimates were made for each event by dividing the path-averaged concentration along the beam by the path-averaged concentration along the entire crosswind direction of the plume.

*Adjusted CF<sub>4</sub> and SF<sub>6</sub> concentrations* for each event were obtained by simply dividing the measured value by the percent plume capture. Note that the adjustments, while not negligible, were actually quite small for these events.

*Final sigma-z values* were calculated for each event by substituting the adjusted concentration (CF<sub>4</sub> or SF<sub>6</sub>) into Equation 2.

**Table 4** presents, for the preliminary settling tanks, the derivation of event-specific sigma-z curves. These curves were developed using the CF<sub>4</sub> and SF<sub>6</sub> data, and are specifically limited to the region across the preliminary settling tanks.

**Table 4.** Derivation of Event-Specific Sigma-z Curves Across the Preliminary Settling Tanks

Arbitrary Event	Sigma-Z Data					
	CF <sub>4</sub> -Based (m)		SF <sub>6</sub> -Based (m)		Coefficients (y=ax <sup>2</sup> +bx)	
	Value	Distance	Value	Distance	a	b
1	1.36	22.3	1.80	46.9	- 0.000919	0.0815
2	1.68	23.6	2.46	49.6	- 0.000830	0.0908
3	1.97	25.8	2.52	54.2	- 0.00105	0.103
4	2.00	24.8	2.94	52.2	- 0.000888	0.103
5	1.75	22.4	2.64	47.0	- 0.000892	0.0981
6	1.61	22.5	2.14	47.3	- 0.00106	0.0954
7	2.20	22.4	2.96	47.0	- 0.00143	0.130
8	2.85	22.3	5.19	46.9	- 0.000697	0.143

The final CF<sub>4</sub>- and SF<sub>6</sub>-based sigma-z values and adjusted downwind distances (from Tables 2 and 3, respectively) are presented in Table 4 for each event. Also presented are the coefficients (“a” and “b”) from the second-degree polynomial ( $y = ax^2 + bx + c$ ) used to represent each curve, where “y” equals the sigma-z value at some downwind distance “x,” and “c” is set equal to zero.

A second-degree polynomial was identified as the equation of choice, as it represents the simplest function which can be constructed to pass through the three known points on the curve (the origin and the two sigma-z measurement points). Because this function is used only to support the emissions back-calculation, we chose this strictly empirical approach to represent vertical dispersion within the very limited region between the upwind edge of the source and the downwind emissions-assessment measurement path. This avoids the need to address complex dispersion modeling issues and associated theoretical assumptions about the shape of the curve within this region.

## CONCLUSIONS

The modified area-source technique has been demonstrated as a preferred alternative to the Eulerian Gaussian and Lagrangian Stochastic approaches for characterizing emissions from AFO-type area sources. In contrast to these latter approaches, this mass-balance alternative does not require consideration of contaminant or meteorological (wind) data in the vertical dimension. The resultant emissions information is inherently more accurate and is generated in a fraction of the time.

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