Texas Natural Resource Conservation Commission

INTEROFFICE MEMORANDUM

To: APD Technical Staff Date: March 6, 2002

From: Dom Ruggeri, Team Leader
Air Dispersion Modeling Team

Subject: Modeling Adjustment Factor for Fugitive Emissions

Procedure

As part of our model refinement process, we developed a new procedure to model fugitive emissions near the ground. The procedure also applies to emissions from sources characterized as pseudo points. The 0.6 adjustment factor we propose will result in more representative predicted concentrations; however, the overall modeling process should still yield conservative results. The adjustment factor can be used with the SCREEN and Industrial Source Complex (ISC) models, as applicable. The factor is applied during the modeling process and cannot be used to lower the emissions represented in the permit application or those that will be included in the Maximum Allowable Emission Rates Table (MAERT).

Since there is a lack of empirical data concerning fugitive releases from all source types we cannot provide further refinement at this time. However, we will continue to tailor our modeling process for individual applicants on a case-by-case basis if they have site-specific empirical data or other mitigating factors. Apply the factor for fugitive release heights that are about 10 meters (m) or less as follows:

Modeling Fugitive Sources Only

Multiply the emission rate by 0.6 for each fugitive source and enter the result into the model.

Or,

Enter the actual emission rate for each fugitive source into the model. Multiply the predicted concentration by 0.6.

Modeling Mixed Sources

Multiply the emission rate by 0.6 for each fugitive source and enter the result into the model.

And,

Enter the actual emission rate for all other source types into the model.

Background

Why did we develop this procedure?

We became concerned during our standard exemption protectiveness review project that concentration predictions for fugitive sources—and point sources with little momentum or buoyancy flux—were too conservative. That is, the model tended to over predict potential concentrations which could lead to technical recommendations that might require costly control strategies to meet air quality objectives with no real improvement in actual air quality. Following are a few of the conservative assumptions related to the issue of low-level fugitive releases.

- Emissions can be quantified. This means that we can estimate the emission rate with a high degree of confidence. This is not the case for fugitive sources. In addition, it is difficult to match meteorological conditions with emissions for batch operations or sporadic operations. For example, a facility could operate several thousand hours a year but exact hours are not known.

- The plume is assumed to be in a steady state and no plume history is considered. Steady state means that both the emission rate and meteorology are constant. No plume history means that each hour's data is assumed to be separate from any other hour's data.

- Wind conditions are assumed to be hourly averages. Fluctuation in the wind flow will cause the plume to meander and could result in more dispersion. If the data were gathered on-site, average wind conditions could be determined, and resulting predictions would be more representative. However, site-specific data are rare, so regional National Weather Service (NWS) data are used.

    - These data represent conditions during the 1-2 minute period before the observation was taken.

    - Wind gusts are not considered. Omission of gusts results in higher predicted concentrations.

- The plume is not allowed to be affected by changes in wind speed and direction as it moves downwind, and conditions are assumed to be constant in the surface boundary layer. The Environmental Protection Agency (EPA) assumes homogeneous conditions in the lower 10m and this assumption is not realistic. For example,

    - plume meander in the horizontal affects the value of the horizontal dispersion coefficient,

    - parameters such as surface roughness, moisture, and heat flux are not directly considered and these parameters affect both horizontal and vertical dispersion,

- wind speed increases with height and a moderate-strong vertical wind shear could cause significant over-prediction errors, and

- the model assumes that "fugitive" sources have no plume rise and does not account for rise due to turbulent mixing.

We were concerned about how the model addresses the dispersion of low-level releases under stable atmospheric conditions and low wind speeds. These concerns are not new and not ours alone. From the issuance of the first EPA modeling guideline nearly 25 years ago, there have been concerns in the modeling, regulated, and public communities about model accuracy and the subsequent impact on air quality management. Therefore, in an effort to refine our modeling tools and procedures we reviewed numerous texts, articles, and reports that described research on the formulation, evaluation, and application of algorithms and models. Our goal was to develop a simple technique that we could use during the modeling process. We found a power-law relationship that met our needs and used it to develop our adjustment factor.

What are the critical parameters in a Gaussian model?

The critical parameters in the current Gaussian models are the effective source height and the dispersion parameters (Weber 1976). Since fugitive releases are assumed to be neutrally buoyant and have no momentum, the effective source height for fugitives is equal to the height of release. With limited empirical data related to plume rise for fugitive releases, we focused on the horizontal and vertical dispersion coefficients, σ_y and σ_z, respectively. These coefficients provide the rate of dispersion in the model, and they are a function of stability and downwind distance. They represent the standard deviation of the plume's concentration distribution in the horizontal and vertical directions, and they are an estimate of plume width.

How were the dispersion coefficients derived?

For those interested in the details, Gifford (1976) and Turner (1996) present detailed summaries of the development of the dispersion coefficients that are currently used by EPA as well as their limitations. In this memo, we will focus on the main limitations related to the dispersion coefficients.

The rural dispersion coefficients we use today are based on the work of Pasquill (1961). Pasquill made several simplifying assumptions related to turbulence measurements in order to make the process to determine standard deviations of wind direction fluctuations in the horizontal and vertical directions, θ and h respectively, easy to use by non-meteorologists. He published several methods to determine dispersion coefficients based on routinely available meteorological data (insolation, wind speed and cloud cover). He used these parameters to define six stability classes (A-F) [strongly unstable (A); moderately unstable (B); slightly unstable (C); neutral (D); slightly stable (E) and moderately stable (F)] and developed

dispersion curves based on a variety of theoretical and empirical data. With a given stability class and distance, one could determine the value of the dispersion coefficients.

Gifford (1961) transformed Pasquill's values of θ and h into standard deviations of plume concentration distribution in the horizontal (σ_y) and vertical (σ_z), commonly referred to as the Pasquill-Gifford or PG coefficients or parameters. Turner (1969) developed a method to convert the qualitative description of insolation needed to determine stability from hourly meteorological observations based on Pasquill's work and published dispersion curves and related equations for each stability class. These coefficients are often referred to as the PGT coefficients and applied to rural conditions.

Briggs (1973) developed equations for urban dispersion coefficients from the McElroy-Pooler (1968) empirical data that account for the effects of increased roughness and heat flux in an urban environment from elevated sources. The Briggs curves were based on neutrally buoyant tracers with various sampling times; the releases were made near the ground in St. Louis. While no height was specifically indicated, it is assumed that the height was at 20m or below. In addition, the data from releases associated with light winds and high stability were excluded from the analysis. Gifford (1976) transformed values from Briggs (1973) into standard deviations of plume concentration distribution into σ_y and σ_z.

Other than your technical judgement, what evidence do you have that the dispersion coefficients may not be appropriate for fugitive releases?

EPA has adopted many practices and procedures that cause the SCREEN and ISC models to predict high concentrations for low-level fugitive releases. We will address three topics in this memo: stability and light winds; sampling time; and boundary conditions.

Stability and light winds

Pasquill (1961) intended that his diffusion categories be used in limited circumstances: wind speed > 2 m/s, nonbuoyant plumes, and flow over open country. Gifford (1975, 1976) reported the results of field tests conducted by a number of researchers that supported Pasquill's hypothesis that diffusion under these conditions would be irregular and indefinite and that measurements of the deviation of wind direction would be required to quantify diffusion under category F turbulence.

For example, Beattie separated Pasquill's stability classification F into two parts. He assigned a classification of "G" to near-calm conditions which Pasquill specifically excluded from his dispersion curves because he assumed that under these conditions the plume wouldn't move significantly from its point of origin. Beattie did not propose a new "G curve." While it was generally assumed that diffusion under category G conditions would be less than under category F, Sagendorf's experiments indicated that under category G conditions, plume transport could be affected by meander caused by deviation in wind direction, σ_θ, greater than 8 degrees and at times 20 degrees or more. Gifford also reported results from studies by

Nickola, Clark and Ludwick conducted under stable conditions between categories E and G and with a wind speed of 1.5 m/s. Observed concentration values corresponded to category C dispersion coefficients. Furthermore, Gifford stated that diffusion data collected by I. Van der Howen indicated that the effective sigma values can range between categories A and F for light wind and stable conditions.

To ensure a consistent approach to modeling was developed, a group of EPA specialists convened to comment on the initial modeling guideline (EPA 1977). They suggested caution when using stability class G. With high stability and low wind speed, large horizontal plume meander is expected. Without adjustment, serious overestimates of short-term concentrations from low-level sources could be predicted. They concurred that the PG curves for σ_y should not used for near ground releases.

EPA initially excluded category G conditions and wind speeds < 2 m/s and suggested a value of 2-3 m/s for stability categories E and F, and 3-5 m/s for stability category E (EPA 1977). Later, EPA combined category G conditions into category F for regulatory modeling and EPA set 1 m/s as the minimum wind speed to use with all stability categories (EPA 1995). Combining the F and G stability categories but using a wind direction deviation value of 2.5 degrees for category F and using < 2 m/s wind speeds added another level of conservatism to the modeled predictions. If the wind speed is < 2 m/s, the wind direction is considered variable. With a variable wind there is no mean wind direction and considerable meander would be expected. Turner (1994) suggested that slight errors in the estimation of wind direction, especially under stable conditions when pollutant plumes are relatively narrow, can result in large errors in predicted concentrations when the task is to estimate concentrations at specific locations.

Sampling time

The PG curves for σ_y and σ_z were based on 3-minute and 10-minute sampling times, respectively (Pasquill 1976). The curves from Briggs (1973) were based on various sampling times but the times for the short distance tests (about 700m) averaged about three minutes. Due to wind meander, one would expect that the value for σ_y for longer averaging times would be larger than those appropriate for three minutes. This meander under light winds is not accounted for in the PGT values for σ_y (Turner 1994). In the vertical, wind meander is not a significant factor. In the opinion of EPA and American Meteorological Society (AMS) specialists (EPA 1977and Hanna 1977), the PG curves for σ_y should be adjusted according to the sampling time using the 1/5 power law. The groups did not address a timing conversion fix for σ_z since sampling time which has a direct effect on wind fluctuation and horizontal dispersion was not the main concern for vertical dispersion.

Boundary Conditions

The treatment of dispersion in the surface boundary layer by the Gaussian model may not be appropriate for near ground-level releases. For practical purposes the surface boundary layer is often defined as that layer in which the shearing stress does not vary by more than 5 percent

(Munn 1966). Usually the reference point is 10m. This is the anemometer height that is recommended by the National Weather Service and World Meteorological Organization (EPA 2000). To solve theoretical equations, researchers have used simple approximations to account for parameters related to turbulence in the surface boundary layer that are difficult to measure and quantify.

According to Munn (1966), a major boundary condition assumption is that shearing stress and wind direction are approximately constant with height if the underlying surface is smooth, the pressure gradient is constant, and the Coriolis force may be neglected. And according to Turner (1969) it's assumed that stability is the same throughout the diffusing layer, and no turbulent transfer occurs through layers of dissimilar stability characteristics. In addition neither the variation of wind speed nor the variation of wind direction with height in the mixing layer are taken into account.

However, Turner (1994) states that near the ground, the increase of wind speed with height due to surface friction is such that it is not possible to select a single wind speed which will be appropriate as a dilution speed; and turbulence is not homogeneous in the vertical due to the presence of the surface. Thus, a moderate-to-strong vertical wind shear could cause significant overestimates of downwind concentrations.

Pasquill (1976) recommended several interim changes in the use of the PG dispersion parameters to account for turbulence in the surface boundary layer. EPA and AMS specialists determined that the PG curves for σ_y should be adjusted to account for increased site roughness or heat flux (EPA 1977and Report 1977). They also suggested that the following quantities are needed to characterize σ_y and σ_z in the surface boundary layer:

- roughness length and friction velocity as measures of mechanical turbulence,
- mixing depth and Monin-Obukhov length, or heat flux as measures of convective turbulence, and
- wind speed and standard deviation of wind direction fluctuations, especially in stable conditions.

EPA has procedures to address many of these issues and recommendations made by Pasquill if site-specific data are available (EPA 2000). However, EPA does not make wind speed adjustments for sources below 10m (EPA 1995). While this restriction may be consistent with the assumptions used to develop the general Gaussian model, it could cause the model to over predict concentrations because wind speeds near the ground are assumed to be the same as those at 10m.

How was the factor derived?

Since we are concerned primarily with low-level fugitive releases, and we believe that σ_y is the controlling parameter, we did not attempt to modify the PGT σ_z curves to account directly for surface roughness and wind shear in the lower levels of the atmosphere. Since there is no simple method to overcome these shortfalls in the model, the continued underestimation of σ_z will maintain a level of conservatism in the process.

To account for the growth of σ_y with increased sampling time due to plume spreading, AMS specialists (Hanna, 1977) recommended that the 1/5 power law proposed by Gifford (1975) be used to adjust the PG curves for σ_y for sampling time. The effect of limited sampling time on the value of σ_y can be represented by the equation:

$$\sigma_{yA}=\sigma_{yB}\left(\frac{t_A}{t_B}\right)^q$$

where σ_{yB} is the standard deviation of the horizontal dispersion averaged over some reference period t_B, and σ_{yA} is the standard deviation of the horizontal dispersion over the time period of interest, t_A. Gifford (1975) reported that most researchers agreed that a value of q on the order of 0.2 was appropriate for t_A values of one hour or less. Using this value results in a factor of about 1.8 for the time ratio of 60 minutes to 3 minutes.

From this relationship, the PGT values for horizontal dispersion are too low by nearly a factor of two, which alone could result in the model's over prediction of concentration by about the same factor. This form of the power law did not meet our needs at this time as we want an adjustment that is easy to apply, and we only want to address the issue of fugitive releases.

Gifford (1975) also discussed a related approach based on concentration instead of dispersion coefficients. Turner (1969) stated that downwind concentrations decrease with time mainly due to increased meander of plume direction, and also proposed that the decrease in concentrations follows a power law. Based on his research, he suggested the equation:

$$X_s=X_k\left(\frac{t_k}{t_s}\right)^p$$

where X_k is the average concentration estimated for a reference period t_k, and X_s is the desired concentration over the time period of interest, t_s. He recommended a value of p equal to about 0.17. To account for the difference between the 3-minute reference times used to develop the coefficients and the 60-minute application period, the equation becomes

$$X_A = X_C\left(\frac{3}{60}\right)^{0.17} = 0.6X_C$$

where X_C is the SCREEN or ISC model prediction based on the EPA convention that the 3-minute coefficients apply for 60-minute averaging periods, and X_A is the concentration we will use to compare to our hourly standards and ESLs. We favor this approach because we can apply the correction to:

- both screening and refined model predictions,
- predicted concentration rather than adjusting dispersion coefficients, and
- emission rate on a source-by-source basis.

In addition, by applying the correction on a source-by-source basis we can

- use the ISCST3 Maxifile option to predict frequencies of exceedance, and
- model mixed source types in one model run.

Is the new procedure still conservative? While the new procedure is not as conservative as the old one, it is still conservative. The old procedure made no direct adjustment for model limitations, instead we used engineering judgement on a case-by-case basis to determine if adjustments to predicted concentrations were appropriate. The previous approach was resource intensive. The new approach will streamline the process without affecting our capability to judge whether a source should cause or contribute to unacceptably high concentration levels. In addition, we are not making any adjustments to other factors that lead to conservative results.

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