A MODEL FOR THE MAXIMUM CREDIBLE HOURLY IMPACT ON ANY GROUND RECEPTOR FROM POINT SOURCES WITH MOMENTUM-DOMINATED PLUME RISE

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Abstract. A pollutant dispersion model is developed, allowing rapid evaluation of the maximum credible one-hour-average concentration on any given ground-level receptor, along with the corresponding critical meteorological conditions (wind speed and stability class) for stacks with momentum-dominated plume rise in urban or rural areas under buoyancy or no buoyancy induced dispersion. Site-specific meteorological data are not required, as the computed concentrations are maximized against all credible combinations of wind speed, stability class, and mixing height.

The analysis is based on the dispersion relations of Pasquill-Gifford and Briggs for rural and urban settings respectively, the buoyancy induced dispersion correlation of Pasquill, the wind profile exponent values suggested by Irwin, the momentum plume rise relations of Briggs, as well as the Benkley and Schulman's model for the minimum mixing heights.

The model is particularly suited for air pollution management studies, as it allows fast screening of the maximum impact on any selected receptor and evaluation of the ways to have this impact reduced. Also, for regulatory purposes, as it allows accurate setting of minimum stack height requirements as function of the exit gas volume and velocity, the pollutant emission rates and their hourly concentration standards, as well as the source location relative to sensitive receptors.

1. Introduction

Dispersion models are a vital element in air pollution management studies as they link source inventories with ambient air quality (Economopoulos, 1987). Their widespread use, however, is hampered by the complexity of existing computer models due to their requirements both in terms of input data and user skills (Economopoulos and De Koning, 1989).

Naturally, the development of simple models has been pursued over many years and numerous studies on the subject have been published. Recent innovations in this area include a seasonal or annual dispersion model for traffic and space heating emissions in urban settings (Economopoulos, in press), as well as a short term model for critical impact analysis of point sources with buoyant plumes, on any ground-level receptor in both urban and rural settings (Economopoulos, 1991). Both models combine notable ease of use with reasonable accuracy, matching that of sophisticated computer models.

In the present paper, a short term dispersion model is presented allowing rapid estimation of the maximum short-term impact of emissions from point sources under momentum-dominated plume rise conditions on any given ground-level receptor. The
practical ramifications of the present model stem from the observation that if a point source is to violate some air quality standards, those which are violated first and foremost are normally the short-term ones. Thus, our model output, the maximum hourly concentration level on any selected receptor, provides a useful yardstick enabling one to decide in many situations whether the overall impact on that receptor is acceptable. More detailed modeling with site-specific meteorological data is advisable in cases where the computed impact exceeds stated limits.

The momentum plume rise becomes dominant when the temperature of the exhaust gas is not much higher than that of the ambient air. This situation is commonly encountered in practice with ventilation gas from fugitive sources and processes, storage and transportation systems (e.g. in fertilizer, textile filament, metallurgical, or nonmetallic minerals processing industries), or with scrubber tail gases.

Relatively unstable pollutants can be dealt with in our model, but flat terrain topography remains a requirement, as in most Gaussian dispersion models.

2. Diffusion of Gaseous or Aerosol Pollutants

Typical assumptions in Gaussian models include that of the normal distribution of plume spread, in both the horizontal and vertical planes, constant eddy diffusivities, steady state conditions, complete reflection at the ground and at the mixing layer under unstable or neutral conditions, as well as stable pollutants, which follow the turbulent motion of the atmosphere. As the objective of this study is to assess the maximum emission impact from a given stack on ground receptors ($z=0$), we are primarily interested in computing the concentrations below the plume centerline ($y=0$). Under such conditions the well known Gaussian diffusion equations can be simplified as follows:

For unlimited mixing or stable meteorological conditions,

$$C = \frac{1}{\pi \sigma_x \sigma_z U_s} \exp \left[ -\frac{1}{2} \left( \frac{H_{\text{eff}}}{\sigma_z} \right)^2 \right].$$  \hspace{1cm} (1)

For limited mixing under unstable or neutral conditions,

$$C = \frac{1}{\pi \sigma_x \sigma_z U_s} \left\{ \sum_{\eta = -\infty}^{\eta = \infty} \exp \left[ -\frac{1}{2} \left( \frac{H_{\text{eff}} + 2nL}{\sigma_z} \right)^2 \right] \right\}. \hspace{1cm} (2)$$

3. Dispersion Coefficients

The standard deviation coefficients $\sigma_x$ and $\sigma_z$ for Equations (1) and (2) are computed through the following equations: