A MODEL FOR THE CRITICAL HOURLY CONCENTRATION, RECEPTOR DISTANCE AND METEOROLOGICAL CONDITIONS FROM POINT SOURCES WITH THERMAL PLUME RISE

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Abstract. A new point source pollutant dispersion model is developed, allowing fast evaluation of the critical one-hour-average ground concentrations, along with the corresponding receptor distance and meteorological conditions (wind speed and stability class) for urban or rural areas, under gradual or final plume rise and with or without buoyancy induced dispersion assumptions. Relatively unstable pollutants can be dealt-with, while 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, as well as against all receptor distances. The model combines, under a constrained numerical extremization algorithm, the minimum mixing height model of Benkley and Schulman, with the dispersion relations of Pasquill-Gifford and Briggs for rural and urban settings respectively, the buoyancy induced dispersion correlation of Pasquill, the power-law wind profile exponent values of Irwin and the buoyant plume rise relations of Briggs. The model is well suited for air pollution management studies, as it allows fast and accurate screening of selected point sources in study areas and evaluation of the ways to have their impact reduced, as well as, for regulatory purposes, as it allows the setting of minimum stack size requirements as function of the exit gas volume and temperature, the pollutant emission rates, and the hourly pollutant concentration standards.

1. Introduction

The critical concentration and receptor distance for a given stack, along with the meteorological conditions leading into it, is important for both air pollution management and regulatory purposes, but cannot be computed directly through regular computer models. Specific models allowing less cumbersome estimation of the above parameters with acceptable accuracy are thus important.

Naturally, the formulation of such models has been pursued over many years, e.g. Ragland (1976), Fortak (1979) and Roberts (1980). These models however, are based on the analytical solution of the critical conditions problem, an approach necessitating the introduction of simplifying assumptions which downgrade the accuracy of predictions. Indeed, in the typical case the dispersion coefficients $\sigma_y$ and $\sigma_z$ are computed as function of the receptor distance through a simple expression of the form $(ax^b)$, which is not always the most appropriate. For example, the well established Briggs dispersion parameter scheme employs considerably more complex functions, as well as changing coefficients over distance. Moreover, the simplifying assumptions of final plume rise and of no buoyant plume dispersion, are implicitly made, but the computed critical conditions can be significantly affected by them, Figures 1 and 4. An additional drawback of existing models is that they
neglect the impact of the mixing height. Ragland (1976) points out correctly that the maximum concentration is twice as high for worst case trapping as for coning. However, the worst case trapping is not always physically realistic, as for example in the case of short stacks in urban areas. As a result, the actual critical concentration can be anywhere over a very wide range. Finally, inherent in the analytic solution approach followed in the development of existing models, is the requirement that, for any given stack, the critical conditions must be computed separately over each stability class, and the predictions must be compared to determine, which among them is the globally critical one. This tends to be a fairly cumbersome procedure, especially when analysing mitigation options.

In the present paper we avoid the above shortcomings by taking a numerical optimization approach, instead of an analytic one, which eliminates the necessity of any simplifying assumptions. Moreover, under the extremization algorithm, a minimum mixing height model is incorporated, which for the first time is combined with the dispersion correlations and solved simultaneously so as to ensure that the computed critical concentrations are based in the most adverse credible (and not simply the most adverse mathematical) mixing height. Finally, a parametric analysis is carried out allowing the presentation of the results in simple graphical form, which enables not only direct reading of the critical impact of a given stack, but also a very convenient, yet fairly elaborate, analysis of the mitigation options (computation of the maximum allowed pollutant emission rates, and/or the minimum stack height requirements, and/or the impact of compounding the effluent gases from multiple stacks).

Our model inputs are restricted to the physical dimensions of the stack, the volume and temperature of the released gas, and the pollutant emission rates. 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 practical implications of the present model stem from the basic observation that if a point source is to violate some air quality standards, these which are violated first and foremost, are normally the short-term ones. Thus, the maximum hourly concentrations, predicted by our model for a given stack, provide a useful yardstick enabling in many situations to decide whether the overall source impact is acceptable or not.

2. Model

2.1. Diffusion of gaseous or aerosol pollutants

Typical assumptions in Gaussian dispersion models include steady state, constant eddy diffusivities, complete reflection at the ground and at the mixing layer (under unstable or neutral conditions), and stable gaseous or aerosol pollutants. For receptors at the ground and below the plume centerline, we get the following simple form of the well known diffusion equation: