Abstract

Modelling and analysis of dispersion of air pollutants in the atmospheric boundary layer is an interesting area of research due to lack of a clear understanding of the nature of turbulence, atmospheric stability and other meteorological parameters. Several diffusion experiments have been carried out to study the characteristics of dispersion of air pollutants for the development of enhanced modelling capabilities. These studies are mainly focused on the dispersion of pollutants release from a single point source. The analysis of dispersion behaviour becomes more complex when the contaminant is released from more than one location at a time. This assumes significance over an urban environment due to the existence of a number of emission sources. Further, the problem becomes even more challenging in the identification of point sources from a set of merged atmospheric concentration measurements. However, in the case of multiple point releases, study of the characteristics of plume dispersion and the performance evaluation of existing dispersion models have not been yet carried out in a consistent manner. Thus, there is a need to study the dispersion of air pollutants emitted from a single as well as multiple point sources using various dispersion models under various wind and stability regimes.

For an efficient source-term estimation, it is important to use an accurate dispersion model with appropriate dispersion parameters. For this purpose, an earlier developed steady-state mathematical model which is formulated assuming advection along the mean-wind, the diffusion along all the three directions, and the constant eddy diffusivities following Taylor’s statistical theory for near source diffusion is utilized. Analytical solution of the resulting parabolic partial differential equation (advection-diffusion equation) with the physically relevant boundary conditions in the model has been obtained using Integral transforms. This model is referred as IIT (Indian Institute of Technology) dispersion model (Sharan et al., 1996). The analysis is carried out by simulating the dispersion of plumes resulted from the available single and multiple releases conducted at Fusion Field Trials, Dugway Proving Ground, Utah 2007 using IIT dispersion model and an operational air-quality model AERMOD (American Meteorological Society/Environmental Protection Agency Regulatory Model). Simulated results from IIT model are compared with those obtained using AERMOD. It is observed that both the
IIT and AERMOD models, predicted peak concentrations of tracer within a factor of two in all the releases and the transport is mostly along the mean wind direction. Similarly, with both the models, the higher concentrations are predicted close to observations in all the trials of stable conditions and within a factor of two in the trials of unstable conditions. The statistical measures for both the models are well in agreement with the observations and a quantitative analysis based on F-test shows that the performance from both the models are found to be similar at 5% significance level.

Application of atmospheric dispersion models in air-quality analysis requires a proper representation of the vertical and horizontal growth of the plume. For this purpose, various schemes for the parameterization of dispersion parameters ($\sigma$'s) under both stable and unstable conditions are critically analysed. The schemes differ on the use of (i) extent of availability of on-site measurements (ii) formulations developed for other sites and (iii) empirical relations. The performance of these schemes is evaluated by IIT dispersion model with the data set in single and multiple releases of FFT-07 experiment for both qualitatively and quantitatively under stable and unstable conditions. The statistical significance of the various schemes is investigated using the blocked bootstrap resampling technique by computing 95% confidence limits on the parameters fractional bias (FB) and normalized mean square error (NMSE). The analysis indicates the consistency in the qualitative and quantitative performances of various $\sigma$ schemes under different stability regimes for single as well as multiple releases. Furthermore, the scheme which is based on standard deviation of wind velocity fluctuations and Lagrangian time scales exhibits a relatively better performance in predicting the peak concentration as well as the lateral spread of the plume.

It has been pointed out in various studies that the commonly large shifts of wind direction, which usually occurs in low and variable wind conditions, are poorly understood and are not sufficiently captured by AERMOD. In such conditions, the observed concentration distribution is multi-peaked and non-Gaussian due to large variability in wind direction. To account the variability in the wind direction in the AERMOD, a segmented approach is used assuming that a shorter time period (2 min) mean wind direction estimates the plume better than the hourly mean wind. For this purpose, simulations are carried
out using AERMOD with segmented approach (2 min averaged mean wind) and utilizing the concentration measurements from the low wind diffusion experiment conducted at Idaho. The qualitative performance of AERMOD using segmented approach is found to be relatively better in terms of explaining the key characteristics such as multiple peaks and large plume spread of the observed concentration as compare to the non-segmented approach. The statistical measures indicate that the results obtained from AERMOD with segmented approach are in well agreement with the observations. In addition to the Idaho experiment, the model is evaluated with the observations from FFT-07 diffusion experiment in both stable and unstable conditions. The model simulated results from the segmenting approach are found to be closer to the observations as compared to the non-segmentation of plume in both stable and unstable conditions.

Identification of a point release is a parametric estimation problem associated with the estimation of its parameters viz., location and strength. A deterministic least-square data assimilation approach (Sharan et al., 2012b), which is free from any initialization is used for identification of the point-source. AERMOD is coupled with this inversion technique for enhancing potential applications of the model as well as the inversion technique for the source identification. Ten trials of single continuous point releases conducted during FFT-07 experiment are chosen for the simulation and further analysis. The computations have been carried out for both synthetic as well as real data in stable and unstable trials. In case of synthetic data, source location and its intensity in all the trials are reproduced precisely. With the real data, the source locations are fairly well retrieved with an average error of 25.5 ± 15 m from their true locations. The source strength is retrieved within a factor of 1.6 in all the trials. This study is useful for emergency regulators to detect an unknown accidental or deliberated continuous point releases.