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Study of Performance analysis of Wind tunnel simulation of pollutant Dispersion Relating street canyon

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Abstract – *Air quality modeling plays an important role in formulating air pollution control and management strategies by providing guidelines for better and more efficient air quality planning. Several line source models, mostly Gaussian-based, have been suggested to predict pollutant concentrations near highways/roads. These models, despite several assumptions and limitations, are used throughout the world, including in India, to carry out air pollution prediction analysis due to vehicular traffic near roads/highways. In this study, the pollutant dispersion within street canyons is studied by experiments conducted in an environmental wind tunnel. The vehicular exhaust emissions are modeled using a line source. The pollutant (smoke) concentrations inside the canyons are measured based on a light scattering technique. The pollutant concentrations within the four different street canyons containing the galleries and the three-level flat-roofs under both the isolated and urban environments are obtained and discussed*

Key Words: Pollutant dispersion, wind tunnel Boundary layer Street, *array of building Obstacles, Vehicular Emission*, *etc*

1. INTRODUCTION

A "street canyon generally refers to a relatively narrow street in-between buildings that line up continuously along both sides[1]. Within the street canyons, the pollutants emitted from motor vehicles have adverse impacts on the health of pedestrians, cyclists, drivers, vehicle passengers and nearby residents [1]. Since the traffic emissions constitute a major source of air pollution in most urban areas, the dispersion of vehicular exhausts inside and over street canyons becomes an important aspect of urban air-quality studies.

Further, the dispersion is dependent on various source parameters and surface layer micro-meteorological parameters such as wind speed, wind direction, roughness conditions etc. In addition, the influence of the nearby buildings and other structures of varying terrain categories cause further complexity in the dispersion phenomenon. Hosker (1984), Hunt (1975) and Meroney (1995) have discussed the complex diffusion mechanisms in the wake of building arrays. Until fairly recently the literature on this topic has been quite sparse; for example the review by Hosker (1984) was mainly concern with flow and dispersion around individual or small groups of obstacles, with only handful of relevant field and wind tunnel experiments have appeared. Meroney (1995) and Hosker (1984) provided excellent reviews on the main characteristics of flow and dispersion around single or small groups of obstacles. Several experiments have been carried out in model and real urban canopies and wind tunnel using tracer gases. Davidson et al. [1995], Theurer et al. (1996), and Macdonald et al. (1998) investigated diffusion around a building in field experiment in suburban area in Sapporo. They found that high concentrations were observed both upwind and downwind of the source on the roof. Macdonald et al. (1998) confirmed that at short distances from the source, concentration profiles in the obstacle arrays are quite variable. Mavroidis and Griffiths (1996) examined the flow and dispersion through arrays of obstacles. The results suggested that enhanced mixing and dispersion occur within array. Recently, dispersion of atmospheric pollutants in the vicinity of isolated obstacles of different shape and orientation with respect to the mean wind direction has been examined in scaled field and wind tunnel experiments. It has been found that the presence of taller obstacles results in a reduction of ground level concentrations [2].

Fig -1: Vehicle fleets in the deep street

2.DEFINITIONS OF TRANSPORT AND DISPERSION

The movement of pollutants in the atmosphere is caused by transport, dispersion, and deposition. Transport is movement caused by a time-averaged wind flow. Dispersion results from local turbulence, that is, motions that last less than the time used to average the transport. Deposition processes, including precipitation, scavenging, and sedimentation, cause downward movement of pollutants in the atmosphere, which ultimately remove the pollutants to the ground surface. This chapter deals only with transport and dispersion.

During the past decade, the complexities of transport and dispersion of airborne pollutants associated with vehicular emissions have been studied with elaborate field and modeling experiments. In the first part of this article, the terms used in the study of transport and dispersion of pollutants and the scales of motion (time and distance) over which vehicular emissions may affect air quality, precipitation quality, or both, are defined. Since pollutants can travel distances from meters to hundreds of kilometers, the relative scales of motion involved in distinguishing transport phenomena from dispersion phenomena may vary from problem to problem.

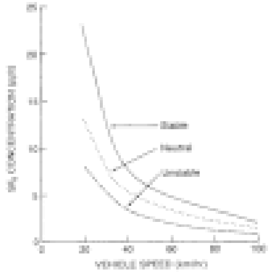

Fig -2: Concentration of SF6 tracer gas versus vehicle speed for unstable.

Transport and Dispersion: Theory and Applications, outlines the observational information on transport and dispersion, describes the theoretical tools that have been used to simulate the transport of vehicular emissions, identifies the limitations of these tools, and recommends specific areas for further research. Mathematical formulations of transport and dispersion are developed only as needed to identify the parameters of interest.

3. SCALES OF MOTION

Human exposure to vehicular-related pollutants is considered in terms of three scales of distance: near field (0.0–0.2 km), urban (0.2–20 km), and regional (20–2,000 km). Direct exposure to primary vehicular emissions may occur inside vehicles as they idle, or from entrainment of air from other vehicles. Generally, vehicular emissions are produced by moving vehicles, but it is also possible for idling vehicles to contribute to high pollutant concentrations, for example, in a parking structure or lot, a street canyon, or a highway queue at rush hour. Consequently, the dispersions associated both with moving vehicles (line sources) and with aggregates of parked or queued vehicles (area sources) are considered. Elevated (nonsurface) emissions from sources such as smokestacks (point sources) are of little importance in the field of vehicular emissions except perhaps when comparing the relative human exposure resulting from surface versus nonsurface emissions on urban and regional scales.

The exposure of humans to vehicular emissions has been studied principally in the near-field environment (0–0.2 km) as will be shown. Exposures in this range are experienced by bicyclists, motorcyclists, pedestrians, people in nearby buildings, and vehicle passengers. This exposure has been fairly well documented for simple configurations in open countryside, but the exposure obtained in complex settings such as street canyons is poorly understood. Knowledge of concentrations on highways is also sketchy. In terms of human exposure, however, this information is critical. Air entering a vehicle or breathed by a cyclist is a direct sample of initially mixed emissions. Hence, understanding the initial mixing process is very important in estimating exposure.

Exposures obtained on an urban scale (0.2–20 km) due to the mixture of vehicular and nonvehicular emissions are also fairly well documented. Urban-area exposure to primary pollutants has generally declined due to improvements in emission control technology. However, some urban areas of high exposure still exist, as mentioned previously, and these problems are generally exacerbated by a combination of adverse meteorological conditions and topographic constraints. Secondary pollutants formed from vehicular emissions, such as O3, can become fairly high in urban areas.

Estimating the contribution of vehicular emissions to regional-scale (20–2,000 km) air quality problems is even more challenging. The NO x and reactive hydrocarbon emissions of vehicles are thought to contribute to regional-scale O3 levels and the levels of other oxidizing compounds such as hydrogen peroxide (H2O2) and hydroxyl radical (OH−). These oxidizing agents are known to influence the rate of conversion of SO2 to sulfate (SO4 2−) and NO x to nitric acid (HNO3) and nitrate (NO3 −). Thus, while the direct influence of emitted NO x on acidic deposition is not thought to be large relative to other sources, the indirect influence of vehicular emissions on the production of acidic species is probable but poorly understood.

4. Method and Validation

This study used the Eulerian method to model the air pollutant dispersion. Compared with the Lagrangian method, which considers the species as a discrete phase, the Eulerian method considers phases as continuum and is solved based on a control volume, which is similar in form to that for the fluid phase (Wang, Lin, & Chen, 2012; Zhang & Chen 2006). Wang, Lin and Chen (2012) compared the performance of Reynolds-averaged Navier-Stokes (RANS) model with

Eulerian method and Large Eddy Simulation (LES) model with Lagrangian methods. The later one is more accurate but also with higher computational cost. Zhang and Chen (2006) used a user-defined function in Fluent to calculate the pollutant concentration, because the lagrangian method does not direclty output the concentration value. Therefore, the Eulerian method is more convenient for calculating the air pollutant concentration, which was the index that this study used to evaluate air pollutant dispersion[4].

In this study, the wind tunnel data provided by Niigata Institute of Technology was used to validate the Eulerian method. The effects of the different turbulence models on air pollutant dispersion simulation were also investigated in this validation study. RANS and LES models were included in the validation study. In RANS models, the standard and realizable model. The model configurations were set to match those in the wind tunnel experiment too. The H/W and H/L aspect ratios were set to 1.0 and 0.5, respectively, where H is the building height, W is the width of the street, and L is the length of the canopy. All modeling settings followed the Architectural Institute of Japan (AIJ) guidelines.

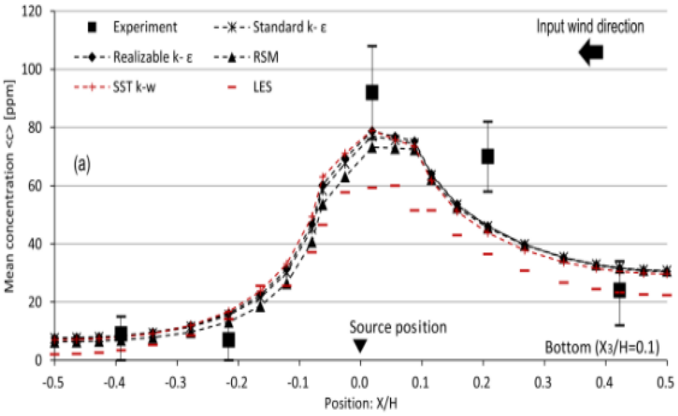

Fig -3: Cross-comparisons of time-averaged concentrations

The simulation results of the different turbulence models were collected at two test lines and cross-compared in Figure 3 The simulation results were closer to the experiment data particularly near ground (X/H=0.1, X is the height of the test line). However, compared with LES model with best accuracy, all RANS models overestimated the concentrations at upper lines (X/H=0.5, for example), particularly at the windward side of the street canyon. Among the RANS models, the SST κω model best performed in terms of air pollutant modeling at the windward side. The special near-wall region (the shear layer) treatment by the standard κ- ω model (Menter, Kuntz, & Langtry, 2003) was considered helpful for estimating the air pollutant concentration near surface regions[5]. Balancing the computational cost and accuracy, for this study, the SST κ- ω model was selected as the preferred turbulence model to simulate the air pollutant dispersion in the parametric study.

4. CONCLUSION

The concentrations of pollutants that would be expected in the absence of moving vehicles are determined by emissions rates and the complex wind flow and turbulence produced by the interaction of the local wind with complex structures (for example, buildings, sound barriers, other vehicles). Weather plays a role in most of these components, generally causing higher emission rates at lower temperatures, diluting pollutants at higher wind speeds, mixing pollutants vertically during unstable thermal conditions, and influencing the rates of homogeneous and heterogeneous chemical reactions and the rate of scavenging of pollutants from the atmosphere by precipitation and dry deposition.

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