# Physical Simulation of Automobile Exhausts Dispersion at an Urban Intersection – Part II: Traffic Induced Effects

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## Abstract

**Traffic induced turbulence coupled with natural air motions becomes an important variable affecting the dispersion of exhaust emissions, especially under low wind conditions. A flexible model vehicle movement system (*f*-MVMS) for an urban intersection having two-way straight and radial peripheral traffic flows has been designed, fabricated and made operational in the EWT to study the traffic induced effects. The tracer gas concentration is measured, online, at hundred ninety two locations by gas chromatograph (FID type detector) at variable approaching wind directions, i.e., $0^0$, $30^0$ and $60^0$ and traffic volumes of 1200, 3300 and 5400 veh/hr. The percentage reduction in normalized concentration (K) values increases with increase in the traffic volume (*'no traffic' conditions to 5400 veh/hr*) and approaching wind angles (*$0^0$ to $60^0$*). The maximum reduction in tracer gas concentration is 47% at $0^0$ and $30^0$ approaching wind directions when the traffic volume is 5400 veh/hr. The percentage reduction is significantly influenced when traffic and wind flow directions are opposite to each other. However, the reductions in K values decrease with height and reach its minimum value of 1.13% at the top of building blocks for all traffic volumes. At 'innermost' corners of the building blocks (facing the intersection), the percentage reduction in K values is more than at 'mid' sections of the building blocks.**

***Keywords***: *urban intersection, model vehicle movement system, heterogeneous traffic, line source dispersion, traffic induced effects*.

## 1.0 Introduction

The highest pollutant concentration within street canyons/congested intersections is generally observed during 'low wind' conditions. In this situation, the amount of turbulence produced by the natural winds within the street canyon/intersection is considerably small than that produced by the moving vehicles. Therefore, one significant question for researchers is the influence of traffic-induced turbulence on exhaust dispersion and its contribution in concentration reduction. Kitabayashi et. al. [1] and Kitabayashi [2] have reported the traffic induced effects on automobile exhaust gas diffusion in typical street canyon at variable vehicular speeds. Bearman and Karanfilian [3], Eskridge and Thompson [4], Eskridge and Rao [5], and Thompson and Eskridge [6] have reported wind tunnel simulation studies on the wake behind vehicle models in 'calm' conditions in a shear free ABL. Contemporarily, Plate [7] has proposed a similarity criterion for wind tunnel modeling of the vehicle and wind induced components of turbulent motion in an urban street canyon. Holscher et al. [8] have conducted wind tunnel simulation experiments to investigate the effects of traffic induced turbulence on micro scale dispersion of pollutant in the vicinity of roadways at different wind road inclinations and wind speeds. Gowda [9], Ahmad et. al. [10] and Khare et. al. [11] have investigated the effects of varying traffic parameters (such as traffic volume, speed) and vehicle model shapes and sizes on line source dispersion in the near field of urban roadways. Pearce and Baker [12] and Pearce and Baker [13] have also reported the effect of vehicular motion on dispersion of pollutants in urban canyons. Baker and Hargreaves [14] conducted the wind tunnel study of pollution dispersion in the wake of a moving vehicle in a crosswind direction for both rural roadways as well as urban street canyon. In an another study, Kastner-Klein et. al. [15] and Kastner-Klein et. al. [16] have experimentally verified the Plate (1982) similarity criterion. The above-mentioned investigations have been carried out either in the near field of roadways or in street canyons. There are few reported studies [17 and 18] on line source dispersion at urban intersections but traffic induced effects have not been taken into account. As a consequence, there exists a gap in systematic understanding of influence of traffic on line source dispersion mechanisms in the close vicinity of urban intersection. In Indian context, the vehicle fleet in the urban intersection is heterogeneous in nature. The present study aims at an in-depth experimental investigation of the heterogeneous traffic induced effects on line source dispersion in close proximity of an urban intersection, including the effects of varying traffic and meteorological parameters.

## 2.0 Experimental setup

The experimental set up, including constructional features of the EWT; simulation of atmospheric flow equivalent to urban terrain, urban intersection, line source and tracer gas sampling and analysis setup have been described in K. Ahmad et. al. [19]. The detailed design of *f*-MVMS has been described elsewhere [10].

## 3.0 Experimental methodology

*Meteorological parameters*

Neutrally stratified ABL equivalent to urban terrain category is selected to carry out the experiments due to high mixing of pollutants in the close vicinity of urban street canyons/intersections, which may cause minimum temperature gradient effects. Plate [7] has reported that in the close vicinity of urban streets/intersection neutral stability condition can be employed. In the present study, three approaching wind directions i.e., $0^0$, $30^0$, and $60^0$ have been simulated having low wind speed conditions (1.5 m/s).

*Real time traffic parameters*

The traffic volume and speed at an urban intersection has been chosen as follows:

During peak hours (9:30 am to 11:30 am and 5:30 pm to 7:30 pm)

Maximum traffic volume: 5400 veh/hr
Maximum traffic speed: 15 km/hr

During moderate hours (11:30 am to 5:30 pm and 7:30 pm to 9:30 pm)

Maximum traffic volume: 3300 veh/hr
Maximum traffic speed: 25 km/hr

During lean hours (9:30 pm to 9:30 am)

Maximum traffic volume: 1200 veh/hr
Maximum traffic speed: 35 km/hr

The heterogeneous traffic conditions (consisting of 33% bus and truck models and 67% car models) and corresponding traffic directional movements at an urban intersection have been simulated in the EWT (Fig. 1).

*Sampling and analysis of tracer gas*

The details of sampling point locations, tracer gas sampling and analysis procedure and normalization of wind tunnel generated data have been described elsewhere [19].

## 4.0 Results and discussion

This section analyses the traffic-induced effects on the dispersion characteristics (normalized concentration, K) of the pollutants at variable traffic volumes of 1200 veh/hr, 3300 veh/hr, 5400 veh/hr and at approaching wind directions of $0^0$, $30^0$ and $60^0$ with respect to the line source. The street cross sections - A to B, B to C, C to D and D to A and the corner cross sections - A to C and B to D are considered for investigating the traffic- induced effects on the normalized concentration (K).

### 4.1 Traffic induced effects at $0^0$ approaching wind direction

Fig. 2 and Fig. 3 show the vertical concentration profiles of K for street cross sections - A to B and C to D, respectively. A significant reduction in K is observed at the receptor heights (z/Z = 0.08) of various locations of street cross sections - A to B and C to D. It may be due to the larger sized traffic induced eddies resulting into increased dispersion at that height. The percentage reduction in K values increases with increase in traffic volume. The maximum percentage reduction (38.2%), is observed at the street width, w/W = 0.6, from A and w/W = 0.4, from C (traffic volume = 5400 veh/hr). Similar trends are observed for other traffic volumes. Further, the K values decreases with height and becomes minimum at z/Z = 0.96 (VI-floor of the building block). However, lesser reduction in K values (in the range of 1.5% to 6.7%) is observed at top of the building block when the approaching wind and traffic movement directions are opposite to each other. It may be due to breaking up of large sized eddies to smaller ones with increase in height, resulting into lesser dispersion of pollutants. Kastner-Klein et. al. [15] and Kastner-Klein et. al. [16] have also observed similar phenomenon along the walls of street canyon in their wind tunnel experiments. The normalized concentration profiles at the corners of the building blocks [Fig. 4(a) and (b)] show that K value decreases with height. The maximum reductions in tracer gas concentration, 47%, 47%, 39.5% and 39.5% are observed at corners A, B, C, D, respectively (at A and B, w/W = 0.2 and C and D, w/W = 0.8) for traffic volume of 5400 veh/hr. The results of upwind corners (inner most corners, A and B) show more reduction in tracer gas concentration than that at downwind corners (inner most corners, C and D).

### 3.2 Traffic induced effects at $30^0$ approaching wind direction

Fig. 5, 6 and 7 show the vertical concentration profiles of K for street cross sections - A to B, B to C, C to D, and D to A, respectively. A significant reduction in K has been observed at the receptor heights (z/Z = 0.08) of various locations of the intersection. It may be due to the larger sized traffic induced eddies resulting into increased dispersion at that height. The percentage reduction in K values increases with increase in traffic volume. The maximum percentage reduction (41.7%), has been observed at the street width, w/W = 0.6, from A and w/W = 0.4, from C (traffic volume = 5400 veh/hr). Similar trends have also been observed for other traffic volumes. Further, K values decreases with height and becomes minimum at z/Z = 0.96 (VI-floor of the building block). However, lesser reduction in K values (in the range of 1.1% to 5.9%)

is observed at top of the building block when the approaching wind and traffic movement directions are opposite to each other. It may be due to the breaking up of large sized eddies to smaller ones with increase in height from the EWT floor and so resulting into lesser dispersion of pollutants. The slight reductions in K values are also observed in the adjacent street C to D. The normalized concentration profiles at the 'innermost' corners facing the intersection [Fig. 8(a) and (b)] show that K value decreases with height. The rate of decrease is higher than at other sampling locations. The maximum reductions in tracer gas concentration, 47%, 47%, 39.5% and 39.5% are observed at the 'innermost' corners facing the intersection A, B, C, D, respectively (at A and B, w/W = 0.2 and C and D, w/W = 0.8) for traffic volume of 5400 veh/hr. The results of upwind corners ('innermost' corners facing the intersection, A and B) show more reduction in tracer gas concentration than that at downwind corners ('innermost' corners, C and D). It may be due to congestion of traffic wakes, which slightly suppress the concentration of tracer gas, resulting less reduction in the downwind corners.

### 4.3 Traffic induced effects at $60^0$ approaching wind direction

Fig. 9, 10 and 11 show vertical concentration profiles of K for street cross sections - A to B, B to C, C to D, and D to A, respectively. A significant reduction in K has been observed at the receptor heights (z/Z = 0.08) of various locations as seen in previous case. The maximum percentage reduction (44.7%), has been observed at the street width, w/W = 0.6, from A and w/W = 0.4, from C (traffic volume = 5400 veh/hr). Similar trends have been observed for other traffic volumes. Further, K values decreases with height and becomes minimum at z/Z = 0.96 (VI-floor of the building block). However, lesser reduction in K values (in the range of 1.4% to 3.8%) is observed at top of the building block (z/Z = 0.96) when the approaching wind and traffic movement directions are opposite to each other. It may be due to the breaking up of large sized eddies to smaller ones with increase in height from the EWT floor and so resulting into lesser dispersion of pollutants. The normalized concentration profiles at the corners of the building blocks [Fig. 12(a) and (b)] show that K value decreases with height. The maximum reductions in tracer gas concentration, 41.8%, 44.3%, 45.1% and 42.5% are observed at 'innermost' corners A, B, C, D, respectively (at A and B, w/W = 0.2 and C and D, w/W = 0.8) for traffic volume of 5400 veh/hr. The rate of decrease is higher than at other sampling locations.

## 5.0 Conclusions

The traffic-induced effects seem to greatly influence the tracer gas concentration depending upon the approaching wind direction. The study reveals increase in the rate of reduction of normalized concentration (K) values with increase in approaching wind angles. 'K' reaches its minimum value at $60^0$ approaching wind direction. It is due to generation of larger size eddies by moving traffic resulting into more dilution in tracer gas concentration (Gowda, 1999). The directional movements of traffic and wind flows also affect K values. The results at $0^0$, $30^0$ and $60^0$ approaching wind directions show more reduction in K values when traffic and approaching wind directions are opposite to each other. The height of building blocks also affects significantly the dispersion of tracer gas concentration. The percentage reduction in K values decreases with increase in height for all traffic volume and approaching wind directions. It reaches its minimum value ($K = 0.58*10^6$) at top of the building block (z/Z = 0.96). The reason for this may be the breakup of larger size eddies into smaller ones, resulting into less dilution and dispersion. The 'inner most' corners facing the intersection are having increased rate of percentage reduction in K values at all approaching wind directions when compared to other locations. It may be due to rapid upward movement of larger size eddies influenced by the corner vortices.

## References

[1] K. Kitabayashi, K. Sugawara and S. Isomusa, A wind tunnel study of automobile exhaust gases diffusion in an urban district, In Proceedings of the 4rth International Clean Air Congress edited by S. Kasuga, N. Suzuki, T. Yamada, G. Kimusa, K. Inagaki and K. Onoe, The Japanese Union of Air Pollution Prevention Association, pp. 192 – 195 (1977).

[2] K. Kitabayashi, Wind tunnel experiments for automobile exhaust gas diffusion in a street canyon, 4rth international workshop on wind and water tunnel modelling, Karlsruhe (1988).

[3] P.W. Bearman and S. Karanfilian, The wakes of road vehicles. In the modelling of dispersion of transport pollution, Symposium proceedings series no. 22, the Institute of Mathematics and its Applications, U.K., pp. 78 – 96 (1981).

[4] R.E. Eskridge and R.S. Thompson, Experimental and theoretical study of the wake of a block shaped vehicle in a shear free boundary flow, Atmospheric Environment, 16 (1982) 2821 – 2836.

[5] R.E. Eskridge and S.T. Rao, Turbulent diffusion behind vehicles: Experimentally determined turbulence mixing parameters, Atmospheric Environment, 20 (1986) 851 – 860.

[6] R.S. Thompson and R.E. Eskridge, Turbulent diffusion behind vehicles: Experimentally

determined influence of vortex pair in vehicle wake, Atmospheric Environment, 21 (1987) 2991 – 2997.

[7] E.J. Plate, Windkanalmodellierung von Ausbreitungsvorgangen in Stadtgebieten. Kolloquiumsbericht Abgasbelastungen durch den Strabenverkehr, Verlag TUV Rheiland, Germany (1982).

[8] N. Holscher, R. Hoffer, H.J. Neimann, W. Brilon and E. Romberg, Wind tunnel experiments on micro scale dispersion of exhausts from motorways, The Science of the Total Environment, 134 (1993) 71 – 79.

[9] R.M.M. Gowda, Wind tunnel simulation study of the line source dispersion in the nearfield of roadways under heterogeneous traffic conditions. Ph.D. Thesis, Indian Institute of Technology, Delhi, India (1999).

[10] K. Ahmad, M. Khare, and K.K. Chaudhry, Model vehicle movement system in wind tunnels for exhaust dispersion studies under various urban street configurations, Journal of Wind Engineering and Industrial Aerodynamics, 90 (2002) 1054–1067.

[11] M. Khare, K.K. Chaudhry, R.M.M. Gowda and K. Ahmad, Heterogeneous traffic induced effects on vertical dispersion parameter- A wind tunnel study, Environmental Modelling and Assessment, 7 (2002) 09 – 15.

[12] W. Pearce and C.J. Baker, Characteristics of the fluctuating tracer concentrations measured at pedestrian level around a 1:125th scale wind tunnel model of a part of the city of Leicester, University of Nottingham, Department of Civil Engineering, Report No. FR 96003, (1996).

[13] W. Pearce and C.J. Baker, Wind tunnel investigation of the effect of vehicle motion on dispersion in urban canyons, Journal of Wind Engineering and Industrial Aerodynamics, 67-71 (1997) 915 – 926.

[14] C.J. Baker and D.M. Hargreaves, Wind tunnel evaluation of a vehicle pollution dispersion model, Journal of Wind Engineering and Industrial Aerodynamics, 89 (2001) 187 – 200.

[15] P. Kastner-Klein, R. Berkowicz, A. Rastetter and E.J. Plate, Modelling of vehicle induced turbulence in air pollution studies for streets, Proc.5th workshop on harmonization within atmospheric dispersion modeling, Rhodes, Greece sited at http://www.geo.umnw.ethz.ch/staff/homepages/pkklein/tpt/texte/pkklein/pkklein-rhodes.pdf (1998).

[16] P. Kastner-Klein, R. Berkowicz and E.J. Plate, Modelling of vehicle induced turbulence in air pollution studies for streets, International Journal of Environmental Pollution, 14 (2000) 496–507.

[17] W.G. Hoydysh and W.F. Dabberdt, Concentration fields at urban intersections: Fluid modelling studies, Atmospheric Environment, 28 (1994) 1849 – 1860.

[18] W. Dabberdt, W. Hoydysh, M. Schorling, F. Yang and O. Holynskyj, Dispersion modeling at urban intersections, The Science of the Total Environment, 169 (1995) 93 – 102.

[19] K. Ahmad, M. Khare and K.K. Chaudhry, Wind tunnel simulation study of line source dispersion at urban intersection – Part I: concentration fields and dispersion, communicated to Journal of Wind Engineering and Industrial Aerodynamics (2005).