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Wind Tunnel Experimental Study of Vehicular Emission Dispersion for Double Storied Inline and Staggered Building Configurations under Wake Interference Flow Regime

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ABSTRACT: **Increased concern over a problem of atmospheric pollution in urban areas has highlighted the need for detailed investigations of atmospheric flow and dispersion of contaminants in the vicinity of buildings. The current work has mainly aimed to contemplate the behaviour of plume dispersion in urban developed zone by wind tunnel recreation, considering structures as obstacles at a size of 1:100 inside re-enacted atmospheric boundary layers (ABL) for two storied structures of inline and staggered designs under wake obstruction flow regime. The stature of the structure considered in the wind tunnel represents 7m (H) tallness in the field for two storied structure. Tracer gas fixations were estimated vertical way at downwind separation of 375H, 298H, 179H, 119H from mid of line source. These estimations were taken at chosen vertical heights of (Z) 2.9 H, 5.7 H and 8.6 H for the chose parallel width of Y= 4 H, 8 H and 12 H for two storied celebrated structure models of inline and staggered array configurations for every downwind separation on either side of the centreline. Moreover, the wake obstruction was additionally considered alongside building exhibit configurations in both inline and staggered course of action. In view of the outcomes, it tends to be seen that the variations in concentrations in downwind distances and lateral widths is continuous and gradual in case of staggered array building configurations when compared to inline configurations. This was primarily because of that staggered arrangement of structures in the wind tunnel, which thus act like obstructions in the concentration of downwind dispersion. In both the cases, concentration of the downwind distances was seen up to a depth of 80% of boundary layer. The R-squared estimations of the cases are in the range from 0.91 to 0.9. And it was inferred that both the structure configurations (inline and staggered), the variety in fixation pattern is practically following the perception made in Macdonald and Griffiths research work. In any case, there was a little deviation in the focus fundamentally because of wake interface.**

Keywords: Wind Tunnel, Wake interference, Vehicular Emission Staggered, Inline, Dispersion.

I. INTRODUCTION

Due to the large increase in amount of vehicles in urban zone has come about into a critical increment in emission of different toxins. It is important to know the dispersion phenomenon of contaminants in the air to improve moderation procedures for vehicular emission control. The dispersion of poisons close to the roadways is ruled by the turbulence induced by the vehicles which are proceeding on the roadway. This can be seen because of the cooperation between the wake of vehicle in the climate and nature of dispersion of contaminants produced by the vehicles [1]. Further the dispersion of contaminants in the air relies upon different parameters like speed, direction, roughness condition of wind at the surface layer [2-4]. Furthermore, the structures nearby and surface territory conditions cause additional dispersion of poisons. This phenomenon was clarified by Hosker, Hunt and Meroney [5-7].

In urban scenario, understanding the nature of contaminant's dispersion is very difficult and it involves the communication of plume with numerous barriers. Here, physical modelling is the most suitable technique to get the exact and reasonable outcomes by considering all the parameters of dispersion phenomenon. Air flow study has demonstrated more prominent potential to understand the dispersion of wide scope of toxins. The primary advantage of wind tunnel study is that the control of factors and the economy [8]. Numerous works here have been experimented before using wind tunnel simulation. The majority of these works have not considered wake obstruction structures as obstacles under wake inference flow regime [9-11]. The current experimental work is to understand dispersion phenomenon of contaminant's in near field roadways of urban territories by considering wake interference and different configurations of buildings [12-14].

II. EXPERIMENTAL STUDY IN EWT

To carrying out dispersion investigations of diffusion and flow patterns of pollutants in the urban environment, (EWT) Environmental Wind Tunnel facility is developed at P.E.S.C.E, Mandya district; Karnataka State, India is shown in Fig.1. Total length of EWT is 19.7m (diffuser section is excluded) and 12m is the section of testing length. 1.2 ×1.2m is size of the wind tunnel section and 1.45m is the height of the bottom surface above the level of ground. In this experimental work, building model made of wood cubical fit has been laid on the floor of the entry from line source to entire downwind zone of section. The height of building model was 70mm at 1:100 scale which represent 7m in actual according to Macdonald R.W [8].

In view of density of plan, diverse flow systems have been characterized as cubical arrangement blocks. Fundamental flow systems attributes are exhibited in Table 1. The present works have been directed an isolated harshness flow system for double storied structures for the arrangement region as per Table 2.

Table 1: Characteristic of the flow regime (Macdonald et al.,).

Flow regime	Array spacing	Plan area density (%)
Isolated roughness flow	$S/H > 2.0-2.5$	$\lambda < 8 - 11$
Wake interference flow	$1.0-1.5 < S/H < 2.0-2.5$	$8-11 < \lambda < 16-25$
Skimming flow	$S/H < 1.0-1.5$	$16-25 < \lambda$

Table 2: Flow regime for double storied structure model.

Average building height (m)	Scale	S/H (>2.0-2.5)	$\lambda_{ar}(\%)$ $(<8-11)$	Width	Prototype cubical model H (mm)
7	1:100	2.00	11.0	W=H	70

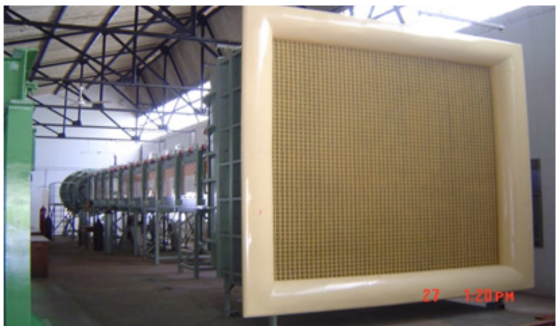


Fig. 1. EWT at PESCE, Mandya.

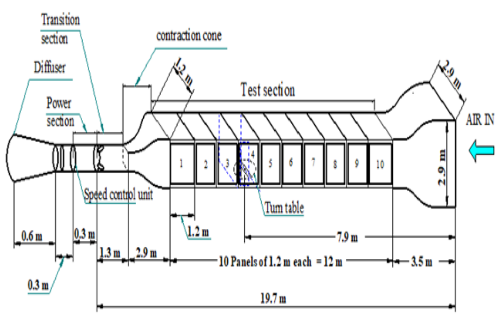
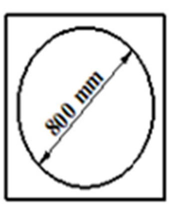
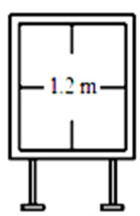


Fig. 2. Layout of EWT.



Turn table in panel no. 4 at test section floor



Cross section of the test section

A. Simulation of ABL flow in EWT

Atmospheric boundary layers (ABL's) is prepared in the wind tunnel from combining passive devices like Counihan's spheres, roughness blocks and Tripping barriers on the floor of wind tunnel, 3 number of elliptic vertexes (Counihan's spheres) of 940 mm height are placed with an initial point of test section EWT. The EWT facility at PESCE, Mandya and its layout is shown in Fig.1 and 2 respectively. The whole floor of the EWT is covered with roughness objects of 23 x 23 x 23 mm of clear distance 70 mm. In addition, a stripping barrier of 300 mm height placed with Counihan spheres at 1.25m. The design of cubical blocks has carried out as per Counihan J [15] and Gowda [16].

B. Mean Velocity Profile in EWT

They are recorded at some selected height intervals above the tunnel floor by traversing hot-wire anemometer (HWA). From entrance of test section (i.e., at the turn table) at 7.9m velocity recordings have been taken. The PC was equipped with data acquisition software (8-channel). The power-law is given by

$$\frac{u}{U_\infty} = \left(\frac{z}{\delta}\right)^{\alpha},$$

Where U_∞ is the mean velocity (i.e., free-stream velocity), δ, and α is the power-law index. From the fig.3 the value was found to be 0.6 for the power law index for the ABL- 3 simulation condition. These values are given in Counihan [15], and Snyder [17] for terrain category of urban areas.

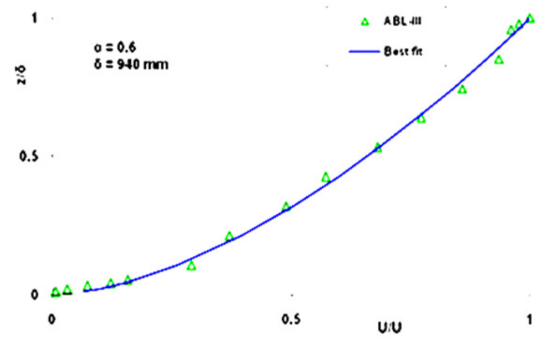


Fig. 3. Average Velocity profile for simulated ABL.

Table 3: Estimated Roughness parameters for the simulated ABL-3.

ABLs	u_* (m/s)	d_0 (mm)	z_0 (mm)	u_*/U_∞	α
ABL - 3	0.268	1.840	0.993	0.0607	0.60

For two storied, a cubical with height (H) 70 mm and spacing (S) 140 mm between beside components, the plan thickness was viewed as 8.5 % (or S/H = 2.4). As given by Macdonald [5] in Table 2, the Prototype cubical models are used for the experiment and are made of wood with size of 1:100, which represents a building height of 7 m. Scale down models size are 70 mm (L) x 70 mm (W) x 70 mm (H).

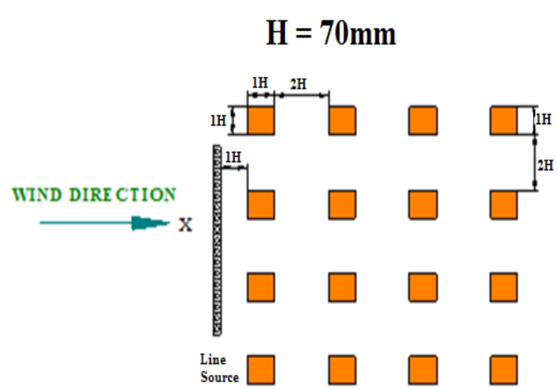


Fig. 4. Inline array building arrangement plan.

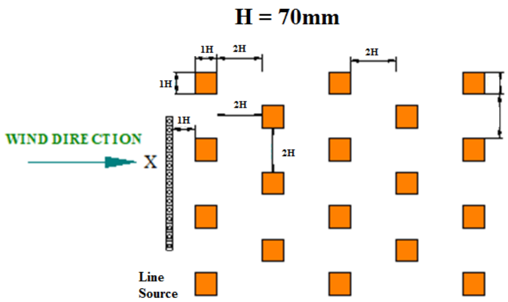


Fig. 5. Staggered array building arrangement plan.

C. Sampling of Tracer Gas and Analysis in EWT

For examination of choppiness levels of the stream field in the EWT & stream of low mean speeds, electronic sensor specifically Hot Wire Anemometer (HWA) was adjusted in the low scope of speeds. An A/D (Analog-to-digital) converter board (ADS774) with important programming was obtained and was introduced in the accessible PC in the research centre. For hydrocarbons tracer gas focus estimations, a Flame Ionization Detector (FID) kind of Gas Chromatograph (GC) of 5765 arrangements (make: Nucon, India) is accessible in the research centre. This setup was made to work for the location, where there are the traces of hydrocarbon gas in the tests with PC handled yield. Tracer gas utilized in the current investigation was said to be 5% acetylene with Grade-I nitrogen, due to its impartially light property. This tracer was gotten by blending pre-determined stream pace of lab graded as, 95.5% acetylene &Grade-I nitrogen (99.9%) into the blending unit. Taking care of separate lines from the acetylene and Grade-I nitrogen bottles were driven through pre-aligned stream meters (i.e., stream rate estimating gadgets) and associated with the blender unit (welding firearm). Directed stream rate was kept up along these taking care of lines by keeping up equivalent pressures at the outlets of acetylene and Grade-I nitrogen gas cylinders by reasonably modifying the control valves.

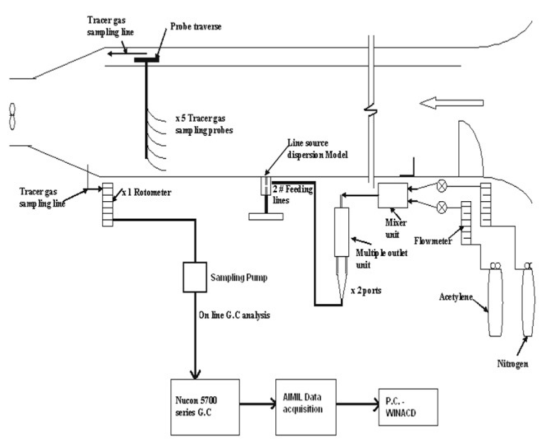


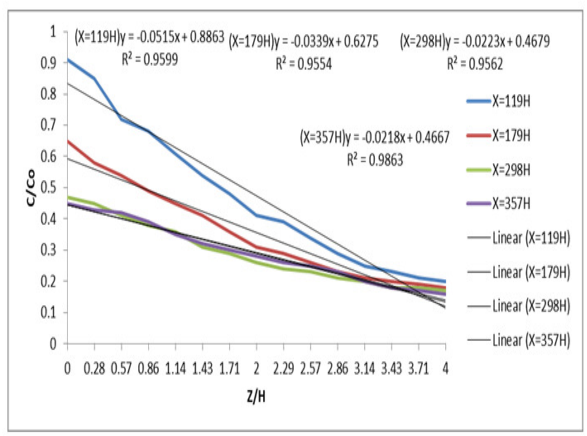
Fig. 6. Diagrametic representaion of line source dispersion.

III. RESULTS AND DISCUSSIONS

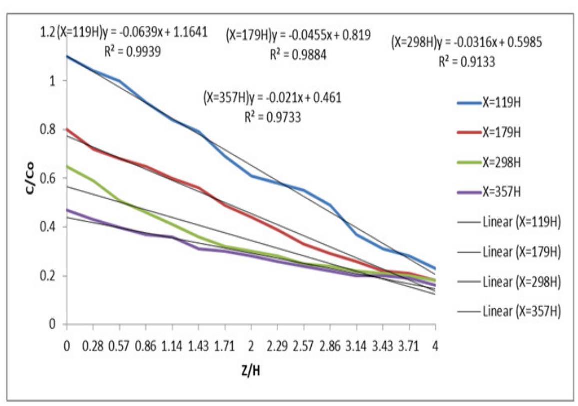
The experiments were conducted in a wind tunnel at stimulated ABL's -3 which shows the middle of a large city with multiple road ways in EWT for in-line and staggered double storied building model arrangements. The analysis for this project was performed with a model scale of 1:100, representing a real constructed building with a height of 7m (double storied building configuration). For the selective downwind distances of X = 119 H, 179 H, 298 H and 357 H from the centre of line source, the variation in vertical concentration were recorded. Readings were taken at selected vertical heights of (Z) 2.9 H, 5 .7 H and 8 .6 H for some of the specific lateral width of Y= 4 H, 8 H and 12 H for double storied building models of in-line and staggered array configurations for downwind distances from both sides of the centreline were obtained and discussed.

A. Concentration variation with downward distance for double storied building inline array confutation with wake interface

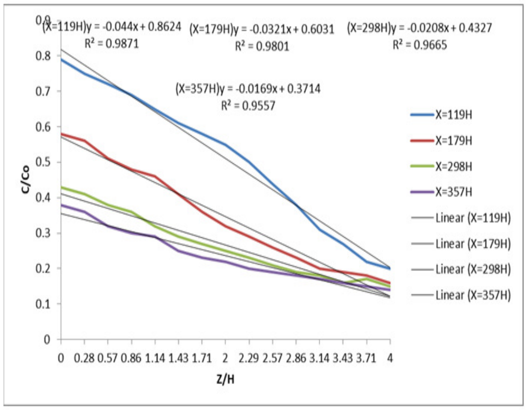
In view of the examination, the watched concentrations over the wind tunnel floor have plotted to consider the vertical fixation profile for the two storied structures model of in-line array configuration. The focus profiles recorded a variation to an extension of 80% of the depth ofboundary layer. Out of the other profiles, vertical fixation profiles have seen to be the best fitted. The squared value of R, is in the scope of 0.91–0.99 and the force law was seen best fitting to vertical focus profiles. From the Fig. 7, it is seen that C/C0 demonstrated a diminishing pattern with increment in height. It is additionally seen that fixation is higher at ground level when contrasted with the higher height. Fixation information shows that upgraded mixing and scattering happened at higher elevations when contrasted with the passage floor for the in-line exhibit setup of the two storied structures model.



(a) Y = 4H.



(b) Y = 8H.

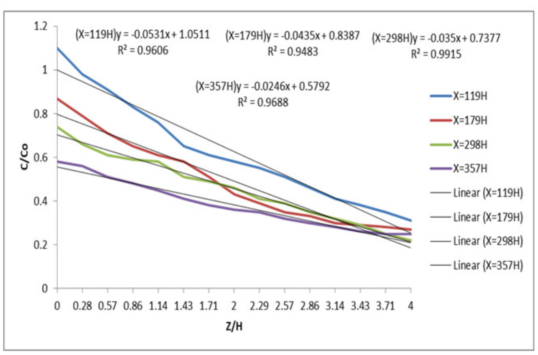


(c) Y = 12H.

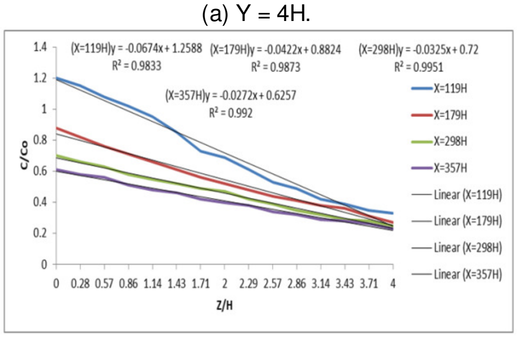
Fig. 7. Concentration variation at selected downward distance for different lateral width for staggered array with wake interface for single storied building.

B. Concentration variation by downwind distances for staggered array configuration for Double storied building with wake interference

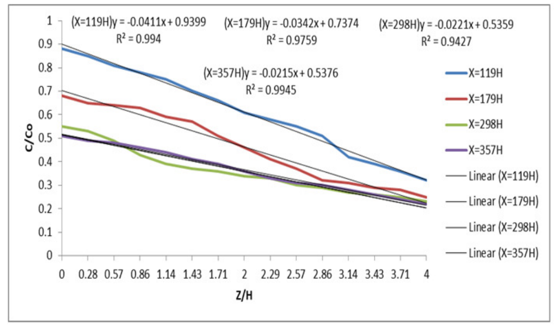
In other case, Fig. 8 depicts the C/Co vs downwind distances Z/H for staggered array arrangements. The graphs show the normalized differences of downwind concentration for two storied array design at Y=12H, 8H and 4H. It is also seen that the concentration variations in downwind distances and lateral widths is gradual as compared with inline building configurations. This is basically due to staggered arrangements of buildings in the wind tunnel, which acts like obstacles to the downwind dispersion of concentration. The squared value of R, is in the range of 0.92–0.96. From both the building configurations, it was observed that the variation in concentration trend is almost following the observation made in Macdonald and Griffiths [18] experimental work. However, there is a little deviation in the concentration mainly due to wake interface.



(a) Y = 4H.



(b) Y = 8H.



(c) Y = 12H.

Fig. 8. Concentration variation at selected downward distance for different lateral width for staggered array with wake interface double storied building.

IV. CONCLUSIONS

Based on the observations made during the study, it is concluded that with the increment increase in height of dispersion the concentrations were diminishing in the direction of downwind. Concentration of tracer depicts higher near to line source than that of downwind distances and further it is observed that concentration observed was maximum at the tunnel floor than at higher elevation. The concentration variation observed in in-line array configuration is diminishing at higher rate in downwind direction as compared to staggered array building configurations. Those of the profiles, the best fitted profile with power law profile were found to be the vertical concentration profiles. The squared values of R, for the cases are in the range of 0.91 -0.99 and are in accordance to that of the vertical concentration profiles. Finally, it is concluded that in both the building configurations (inline and staggered array), the variation in concentration trend is almost following the observation made in Macdonald and Griffiths experimental work. However, little deviation is seen in the concentration which is due to consideration of wake interface.

V. SCOPE OF FUTURE WORK

Investigation with other approaches can be involved to study the vertical spread parameters like different roughness and building configurations to understand the vertical dispersion of pollutants.

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