Experimental Study of Vehicular Exhaust Dispersion on Single Storied Building of Different Configurations Under Wake Interference Flow Regime

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Abstract: **Objective of the current work is to study the behavior of dispersion of plume in built-up area of cities by wind tunnel simulation, considering at a scale of 1:100 with the buildings as obstacles within simulated atmospheric boundary layers (ABL) for one storied structures of inline, staggered configurations under wake interference flow regime. The height of the building considered in the wind tunnel represents 3.5m (H) height in the field for one storied structure. Tracer concentrations of gas are measured in vertical direction at downwind distance of 375H, 298H, 179H and 119H. Readings were recorded at vertical height of (Z) 2.9 H, 5.7 H and 8. 6 H to selected lateral width of Y= 24 H, 16 H and 8 H for single storied structural models of inline and staggered array configurations. In addition, the wake interference was also considered along with building array configurations in both inline and staggered arrangement. Based on the results, it can be seen that the variation in concentrations in downwind distances and lateral widths is gradual in case of staggered array building configurations as compared to inline building configurations. This was mainly due to that staggered arrangements of buildings in the wind tunnel, which in turn act like obstacles to the downwind dispersion of concentration. In both the cases, the downwind concentrations were observed till 80% of the depth of boundary layer. The R-squared values of the cases are from 0.91 -0.97 range. Finally, the conclusion was that among 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, there was a little deviation in the concentration mainly due to wake interface.**

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

1. 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], [3], [4]. Furthermore, the structures nearby and surface territory conditions cause additional dispersion of poisons. This phenomenon was clarified by Hosker, Hunt and Meroney [5], [6], [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], [10], [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], [13], [14].

2. EXPERIMENTAL STUDY IN EWT

To carrying out dispersion investigations of diffusion and flow patterns of pollutants in the urban environment, Environmental Wind Tunnel (EWT) facility is developed at PES College of Engineering, Mandya district, Karnataka State, India is shown in Fig.1. Total length of wind tunnel is 19.7m and 12m is the section of testing length. 1.2X1.2m is size of the wind tunnel section and at a height of 1.45m above the level of ground. In this experimental work, the construction model made of cubic wood was placed on the floor of the entrance to the entire downwind section. The height of building model was 35mm at 1:100 scale which represent 3.5m in actual according to Macdonald R.W [8].

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 single storied structure model

Average building height (m)	Scale	1.0-1.5<S/H <2.0-2.5	$8\text{-}11<\lambda_{ar}$ <16-25	Width	Prototype cubical model H (mm)
3.5	1:100	1.90	11.89	W=2H	35

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

Fig.1: EWT at PESCE, Mandya

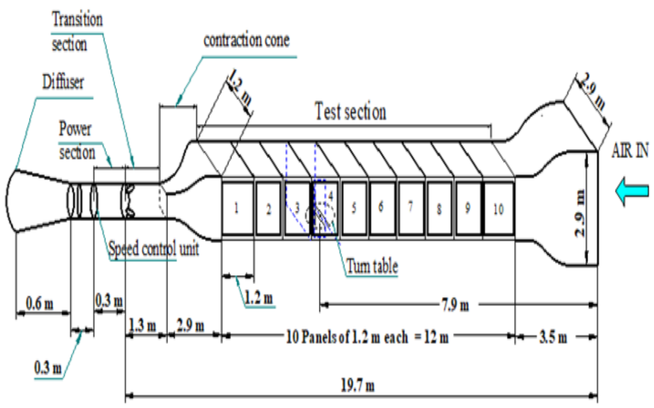
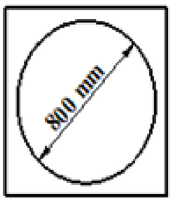
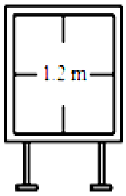


Fig.2: Layout of EWT



Turn table in panel no 4 at test section floor



Cross section of the test section

2.1 ABL Simulation flowingthrough Wind Tunnel

Atmospheric boundary layers (ABL's) is prepared in the wind tunnel from combining passive devices like roughness blocks, Counihan's spheres, and Tripping barriers on the floor of wind tunnel, 3 number of elliptic vertexes (Counihan's spheres) with an elevation of 940mm are placed with an initial point of test section EWT test section. The entire floor of the EWT is secured with harshness objects of 23x 23x 23 mm of clear distance 70 mm. In addition, a stripping barrier of 300 mm height placed with Counihan spheres at 1.25m. Cubical blocks design is processed as per Counihan J [15] and Gowda [16].

2.2 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∞ represents mean velocityδ, and α is the power-law index. The was found to be 0.6 is the power law index (α) for the ABL- 3 simulation condition. These values are given in Counihan [15] and Snyder [17], for terrain category of urban areas.

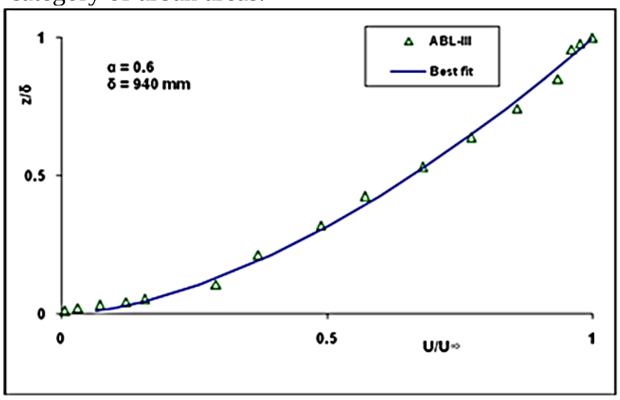


Fig 3: Mean Velocity Profile for Simulated ABL

Table 3: Estimated Roughness Parameters for the Simulated ABL – 3

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

For one storied, a cubical of height(H) 35 mm and spacing(S) 85 mm between beside components, the plan thickness was viewed as 8.5 % (or S/H = 2.4). As shown in Table 2, the modelsthat are used in the experiment are made of wood with scale of 1:100, representing abuilding of height 3.5 m. Scale down model sizes are 35 mm (L) x 35 mm (W) x 35 mm (H).

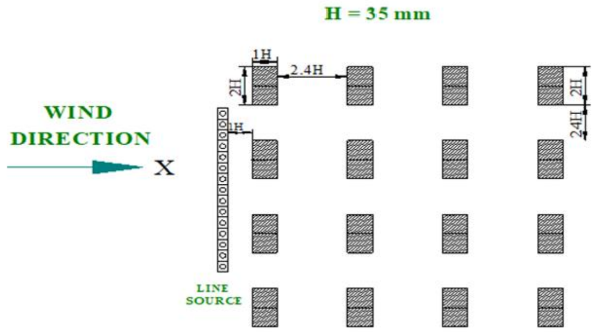


Fig 4: Inline array building arrangement plan

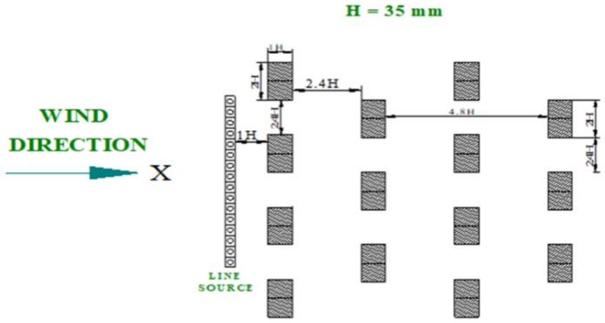


Fig 5: Staggered array building arrangement plan

2.3 Sampling and Analysis of Tracer Gas (hydrocarbons) in Wind Tunnel

For investigation of stream of low average speeds and choppiness levels of the stream field in the Wind Tunnel, Hot Wire Anemometer (HWA) was adjusted in the low scope of speeds. Analog-to-digital (A/D) converter board with important programming was obtained and introduced in the accessible workstation in the research center. For focus estimations of hydrocarbons, a Flame Ionization Detector (FID) kind of Gas Chromatograph (GC) was used. It was made functional for the area of hydrocarbon tracer gas in the tests with workstation handling the yield.Due to its light property, 5% acetylene in Grade-I nitrogen was used for the current investigation of hydrocarbon gas. This tracer gas was obtainedin the blending unit by blending determined stream pace of lab grade acetylene and Grade-I nitrogen. Separate lines for acetylene and Grade-I nitrogen bottles were taken through pre-aligned stream meters which are connected with the blender unit. Directed stream rate was kept up along these lines by maintaining the equivalent outlet pressures at the outlet of the acetylene and Grade-I nitrogen gas bottles by adjusting the control valves.

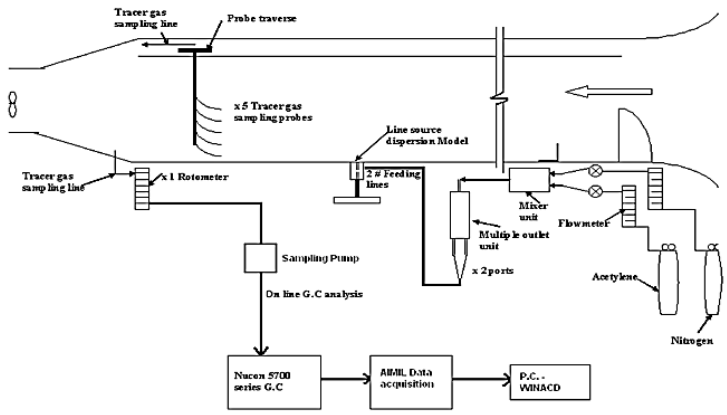


Fig 6: Schematic view of line source dispersion experiment in the EWT

3. RESULTS AND DISCUSSIONS

The investigations were done in wind tunnel at simulated ABL's-3 which shows the focal point of huge city in the close to field of for various single storied structure model configurations. The examination was carried out on a model of scale 1:100, which represents a constructional structure of height 3.5m. The variation in concentration of vertical parameter for selected wind flow distances of X = 357 H, 298 H, 179 H and 119H.The readings were taken at selected elevation of (Z) 8.6 H, 5.7 H and 2.9 H and selected lateral width of Y=24 H, 16 H and 8H forone storied structural models of different array configurations were obtained and discussed.

3.1 Concentration variation in flow distance for single storiedconstructional model of inline array Configuration

In the fig 7., the vertical fixation profile for the single storied structural model was obtained by plotting the observed concentrations on the wind tunnel for inline array arrangement. Up to 80% of the boundary layer depth considered for focus profile. The vertical fixation profiles fit good for the profile. The R-squared value is in the range of 0.85–0.99 and the force law was seen best fitting to vertical focus profiles.It is observed that C/C0 demonstrated a diminishing pattern with increment in height. Also observed 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 bottom for the inline exhibit setup of the one storied structural model.

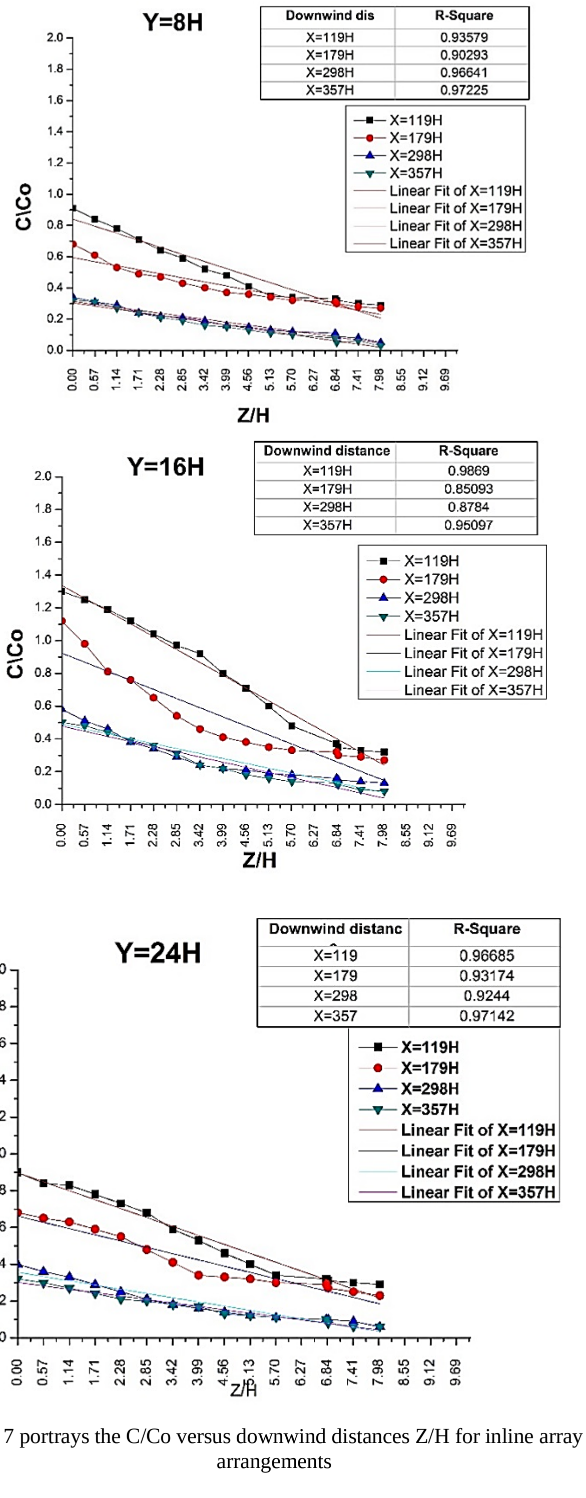


Fig. 7 portrays the C/Co versus downwind distances Z/H for inline array arrangements

3.2 Concentration variation in flow distance for single storied constructional model of staggered array Configuration

Here also, Fig. 8 portrays the C/Coversus downwind distances Z/H for staggered array arrangements The graphs show the normalized differences of downwind concentration for one storied array design at Y=24H, 16H and 8H. 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 *R*-squared value is between 0.92–0.96. From both the building configurations, it was almost 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.

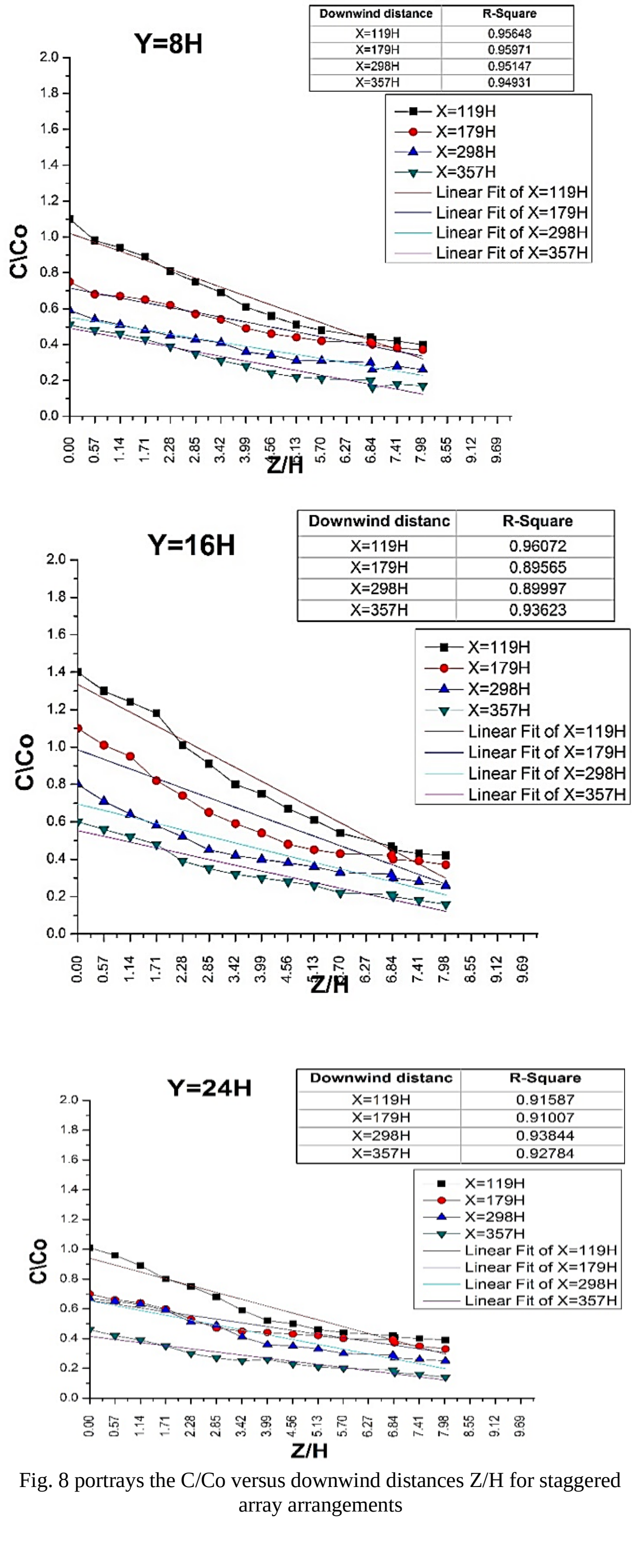


Fig. 8 portrays the C/Co versus downwind distances Z/H for staggered array arrangements

4. CONCLUSIONS

With the increase in height concentration of dispersion is reducing in the down wind direction. Tracer concentration shows higher close to the line source compared to that of downwind distance and furthermore the concentration was maximum at the floor of the tunnel than at higher level. The variation in concentration observed in inline array configuration is decreasing at faster rate in downwind direction as compared to staggered array building configurations. In both the cases, the downwind concentration profiles were shown up to 80% of the boundary layer depth and the vertical concentration profiles fits well. The *R*-squared values are in between 0.91 -0.97. Finally, it is concluded, for both the structural configurations (inline and staggered array), the variation in concentration trend is almost following the observation made in Macdonald and Griffiths (1998) experimental work. However, there is a little deviation in the concentration mainly due to wake interference.

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