An Experimental Study on Vehicular Emission Dispersion Through Single Storied Building Model Configurations

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ABSTRACT*-The problem of plume dispersion around urban buildings has been investigated by physical modelling using arrays of buildings- like obstacles at scale 1:100 in boundary layer wind tunnel for single storied buildings and compared with field data. The particular effect of obstacle width- to - height ratio (S/H) was examined for a fixed obstacle plan area density. In comparison, experimentally observed σ_z values are below the field values. Again, wind tunnel single storied inline array configuration data appears to be more convective and /or less diffusive than the field data. In addition concentration measured in the wind tunnel was consistently larger than field data measurement. This may be due to different roughness conditions simulated in wind tunnel from that of field. The experimental results showed that there were significant differences between non-dimensional concentrations measured in the downwind of the obstacles in inline and staggered array. Even with quantitative differences, the inline and staggered array results showed the same general trend.Study concluded that despite some quantitative differences, the field result and wind tunnel showed the same general trend of vertical dispersion parameter.*

Key words: Atmospheric Boundary Layers, wind tunnel study, vehicular emission dispersion, array of building Obstacles.

1. INTRODUCTION

The problem of near field plume dispersion in the urban environment is quite complex and involves the details of the interaction of the plume and the flow field with several obstacles. This type problem is not generally solvable by computational means and thus physical modeling is the best way to obtain sensible results and to study the influence of the various parameters relevant to the problem. While using any line source model for prediction of pollutants in any urban/suburban area, it is imperative that the model should be capable of accounting for building effects. There is greater scope to understand systematically the influences of important varying parameters on dispersion mechanisms through arrays of obstacles. For the study of these types of local parametric influences, a boundary layer wind tunnel is a convenient tool to investigate the effects of these potential parameters.

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. It is now widely acknowledged that the greatest damage to human health is caused in the near- field of toxic releases from line sources within the urban region. Complex flows around the obstacles in urban canopy pose difficult challenges to research. Thus, it is essential to address these challenges and develop methods to model the impact of contaminants at short distance from the source within urban region.

The main aim of the present paper is to investigate experimentally, the vehicular emission (which are treated as line source) dispersion phenomenon in simulated terrain conditions and to understand the dispersion pattern through single storied building model configurations in the near- field of roadway.

2. EXPERIMENTAL SETUP

2.1. Simulation of ABL Flow

Artificially thickened Atmospheric Boundary Layers (ABLs) have been produced in the Environmental Wind Tunnel (EWT) by the combination of the passive devices such as Counihan's spires, tripping barrier and roughness blocks on the wind tunnel floor. The entire floor of the EWT was covered with roughness elements of 23 x 23 x 23 mm with a spacing of 70 mm (ABL-I). Three number of elliptic vortex generators (Counihan spires) of 940 mm height were placed symmetrically at the entrance of the test section of EWT with roughness elements (ABL-II). Further, a tripping barrier of 300 mm high was placed after the Counihan spires at 1.25 m from the Counihan spires with roughness elements (ABL-III). The design of cubical blocks has been carried out as per Counihan (1969), Gartshore and De Cross (1977) Gowda (1999).

2.2. Details of physical modelling dispersion experiments

In the present study a near-field terrain buildings model arrangements have been selected. The set of experiments were carried for a geometric model scale of 1:100, which represent a real buildings height of 3.5 m (single storied buildings). For this case inline and staggered buildings model configuration were selected.

Physical modelling dispersion experiments were carried out one of the simulated ABL-III which represent centre of large city in the near field of roadway in the EWT. Measurements were taken to obtain vertical tracer gas concentration profiles for single storied building at pre-selected downwind distances of 119H, 179H, 238H, 298H and 357H from centre of the line source as per the scheme shown in Fig. 1. These measurements were observed at selected vertical height of (Z) 2.9H, 5.7H and 8.6H for single storied buildings model for selected lateral width of tunnel from the tunnel floor. For this tracer experiments were carried out for 90°.

Lateral concentration measurements (along width of the test section) for pre selected lateral width of 8H, 16H, and 24H for single storied buildings model for all the downwind distances on either sides of the centreline. Further repeatability checks were carried out for all the experimental observations.

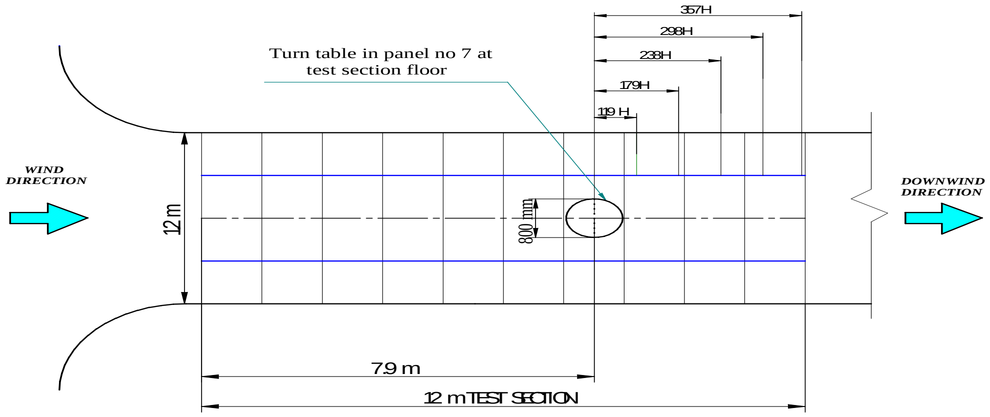

Fig. 1. Schematic showing downwind distances for tracer gas concentration measurement in the E WT

2.3. Experimental configuration in the wind tunnel

For the present study, buildings model made of wood cubical in shape had been arranged on the floor of the tunnel from line source to entire downwind section of the tunnel. The buildings model had been arranged downwind direction of the line source such that the row of buildings was at 35 mm (1H) for single storied buildings. This arrangement ensured that the line source was located in amidst of the buildings model.

Macdonald et al. (1997) characterised the buildings arrangement for arrays of cubical elements by plan area density, λ_{ar}. For regular arrays of cubic elements, the plan area density λ_{ar} is related to the gaps between cubes S and their height H by (eq 1)

$$\lambda_{ar} = \frac{1}{\left(1 + S/H\right)^2}. \tag{1}$$

Where, S= Space between two consecutive array element

Based on plan area density different flow regimes have been defined for arrayed cubical blocks arrangement. The characteristics of these main flow regimes are presented in Table.1. The present studies have been conducted an isolated roughness flow regime for single storied buildings for the plan area density as per the Table 2.

Table. 1. Characteristic of the flow regime (Macdonald et al. [1997])

Flow regime	Array spacing	Plan Area density (%)
Isolated Roughness flow	S/H>2.0-2.5	λ<8-11
Wake Interference Flow	1.0-1.5<S/H<2.0-2.5	8-11< λ <16-25
Skimming Flow	S/H<1.0-1.5	16-25< λ

Table. 2. Characteristic of the flow regime for single storied buildings model

Sl. No.	Average building height in (m)	Scale	S/H (S/H>2.0-2.5)	λar (%) (λar<8-11)	Width	Prototype cubical model H(mm)
1	3.5	1:100	2.40	8.5	W=2H	35

In single storied buildings, cubical model having height (H) 35 mm with spacing (S) 85 mm between elements the plan area density was found to be 8.5 % (or S/H = 2.4). As per the flow regime suggested by Macdonald (1997) in Table 2, the Prototype cubical models used for the experiment are made of wood at a geometric model scale of 1:100, which represent a real buildings height of 3.5 m. Dimensions of the models are 35 mm (L) x 35 mm (W) x 35 mm (H). The size for both inline and staggered array configuration was 8 x 10 arrays. Fig 2 and 3 shows plan view of experimental buildings arrangement in inline and staggered array for single storied respectively.

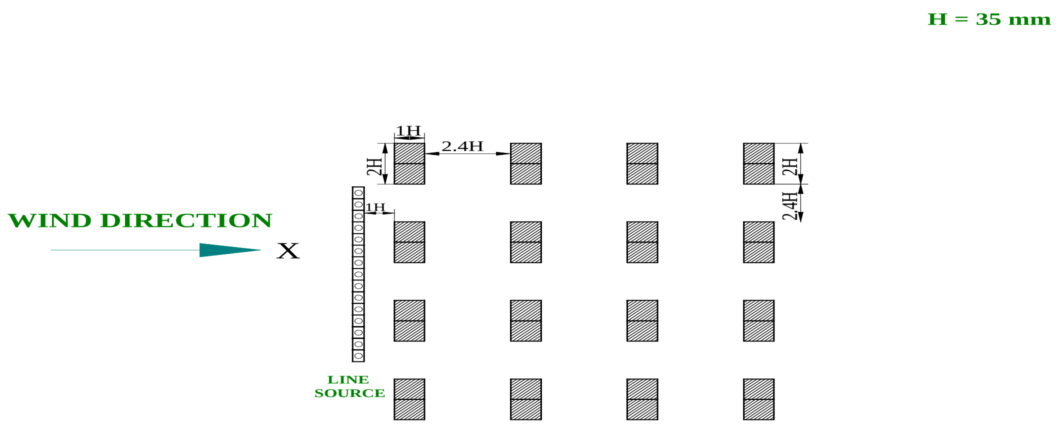

Fig. 2. Plan view of experimental buildings model inline array arrangement for single storied

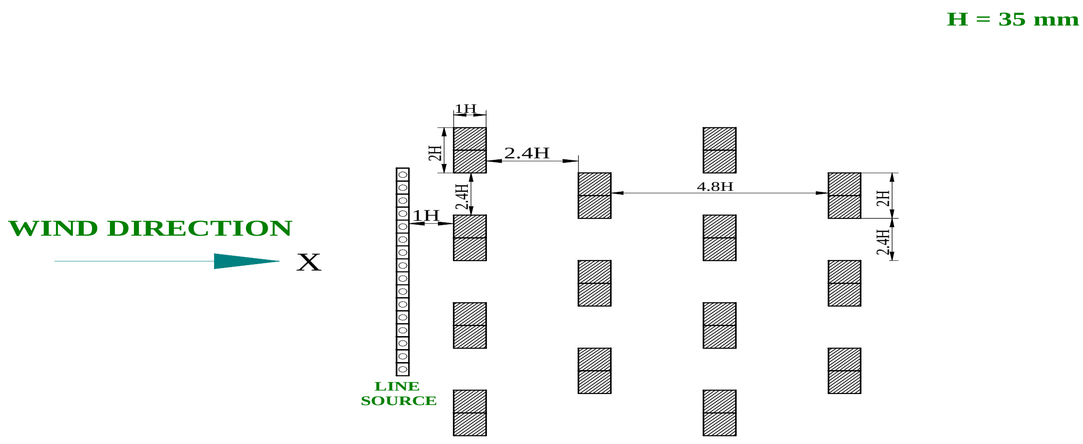

Fig. 3. Plan view of experimental buildings model staggered array arrangement forsingle storied

3. RESULTS AND DISCUSSIONS

3.1. Comparison of Vertical Concentration profiles between Inline and staggered array configuration for single storied Buildings model

The vertical tracer gas concentration profiles were compared at pre-selected downwind distances from centre of the line source at each of the selected lateral widths for single storied buildings model. Fig.4 to 8 depicted the comparison of normalized concentration C/C_o with vertical height Z/H above tunnel floor for inline and staggered array configuration. From the Figures it revealed that vertical concentration values for staggered array configuration are relatively higher than that of inline array configuration at different downwind distances measured. This may be attributed to ‘congestion’ or ‘blocking’ effect (Macdonald and Griffiths, (1997). Gowda, (1999)) which might have produced as a result of, there is another cube located between the obstacles in the staggered array configuration. It can be seen that C/C_o showed decreasing trend with increase in height for both inline and staggered array configuration. In other words, the tracer concentration is maximum at the tunnel floor than at higher elevations.

The experimental results showed that there were significant differences between non-dimensional concentrations measured in the downwind of the obstacles in inline and staggered array. Even with quantitative differences, the inline and staggered array results showed the same general trend.

It was concluded that, C/C_o showed decreasing trend with increase in height for both inline and staggered array configuration of single storied buildings model. In other words, the tracer concentration is maximum at the tunnel floor than at higher elevations. Study also concluded there were significant differences between non-dimensional concentrations measured in the downwind of the obstacles in inline and staggered array. Even with quantitative differences, the inline and staggered array results showed the same general trend.

a) Y=8H b) Y=16H c) Y=24H

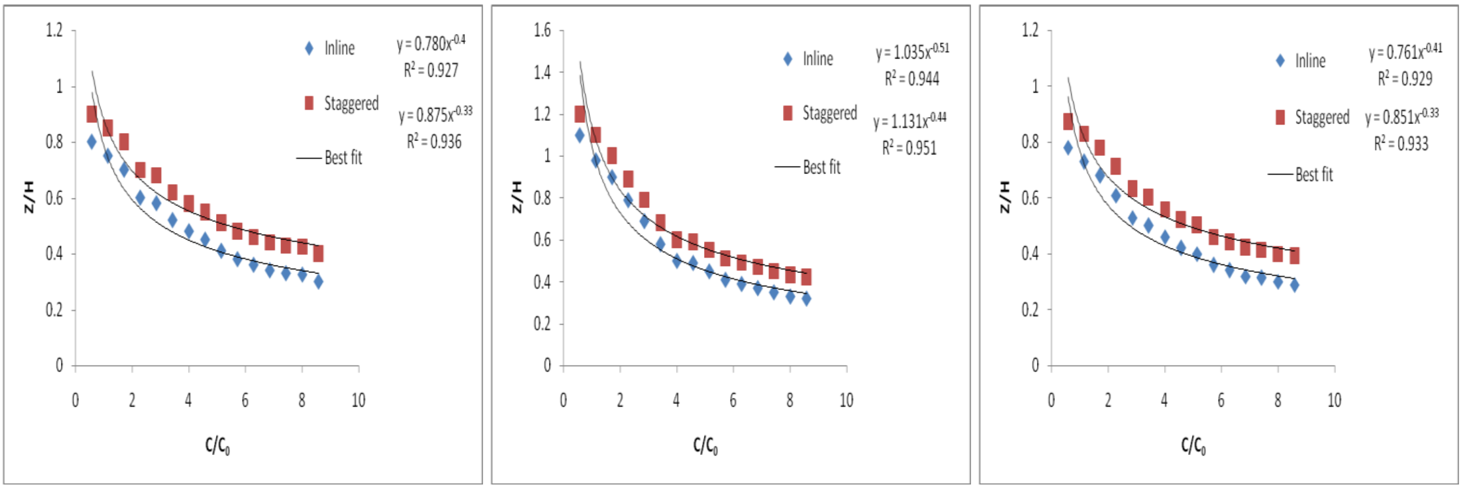

Fig.4. Vertical concentration profiles comparison between inline and staggered array configuration for single storied buildings model at X=119H

a) Y=8H b) Y=16H c) Y=24H

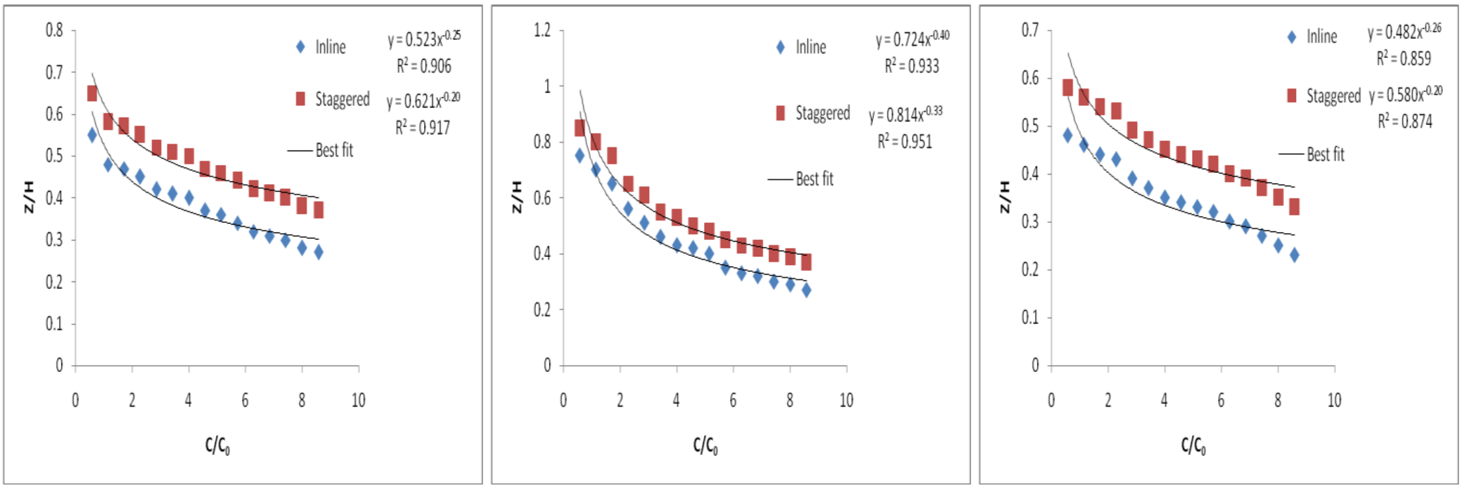

Fig.5. Vertical concentration profiles comparison between inline and staggered array configuration for single storied buildings model at X=179H

a) Y=8H b) Y=16H c) Y=24H

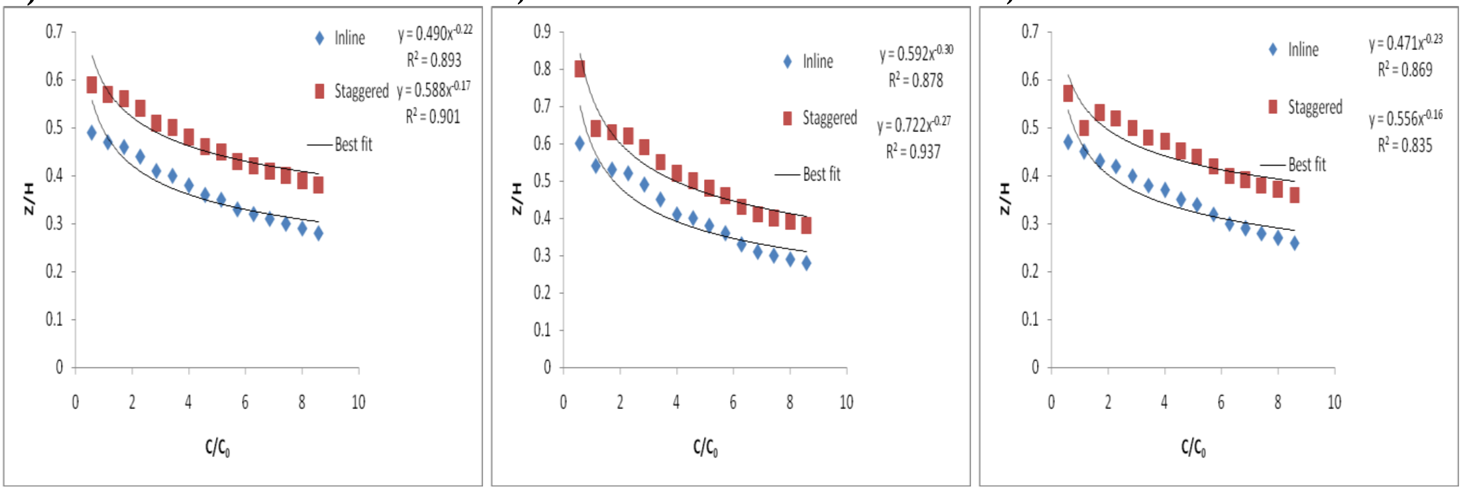

Fig.6. Vertical concentration profiles comparison between inline and staggered array configuration for single storied buildings model at X=238H

a) Y=8H b) Y=16H c) Y=24H

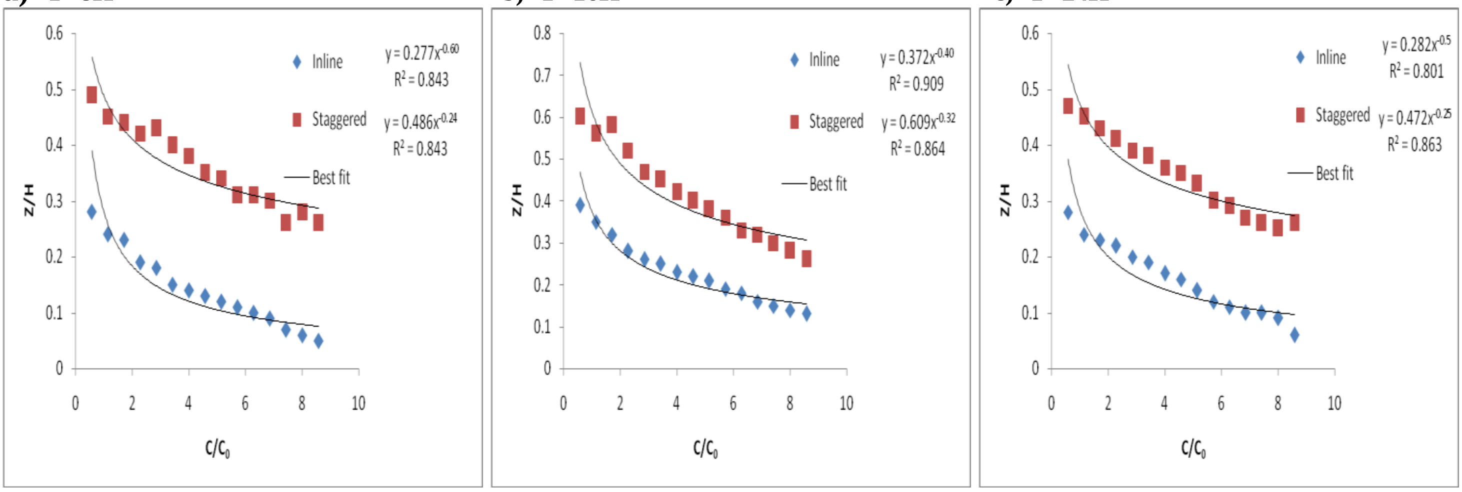

Fig.7. Vertical concentration profiles comparison between inline and staggered array configuration for single storied buildings model at X=298H

a) Y=8H b) Y=16H c) Y=24H

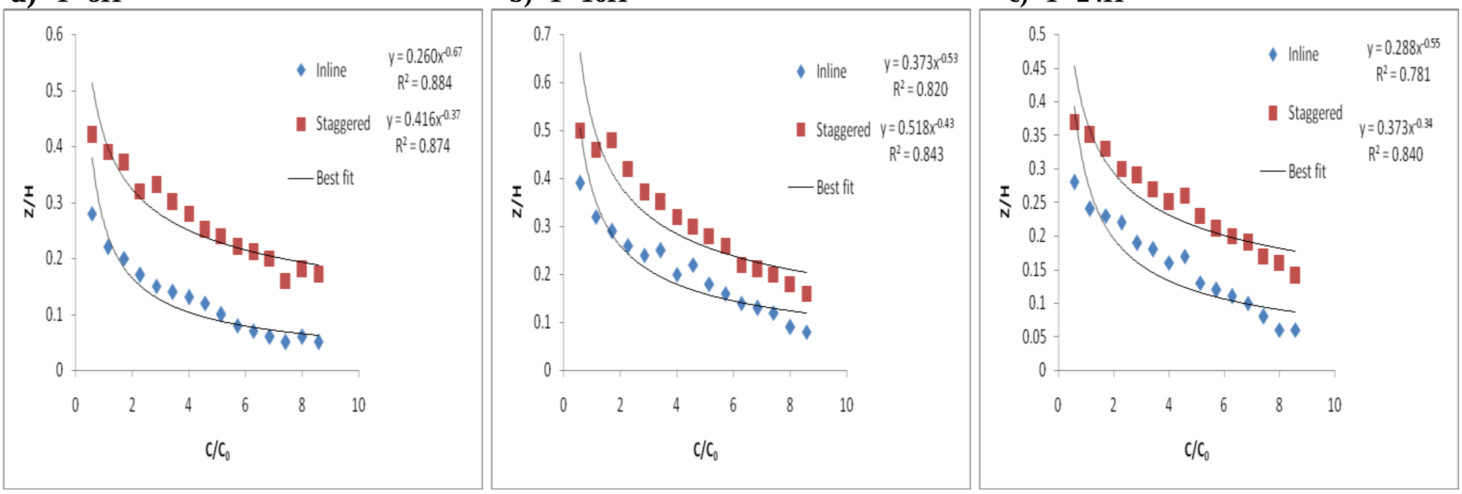

Fig.8. Vertical concentration profiles comparison between inline and staggered array configuration for single storied buildings model at X=357H

3.2. Concentration Variation with Downwind Distance for Single Storied Inline and Staggered Array Configuration

Normalized concentration variation profile C/C_0 verses selected downwind distances X/H for single storied buildings model inline and staggered array configuration were observed. It was evident that downwind tracer concentration maximum near line source (at X=119H) and concentration decreases as downwind distances increases (at X=357H) both inline and staggered array configuration. Similar tracer concentration trend was reported by Macdonald et al. (1997) in their work.

It is evident that centerline concentration relatively higher for single storied buildings model staggered array configuration compare to single storied buildings model inline array configuration at all downwind distance. Thus, it can be concluded that, tracer concentration maximum near line source and it decreases with downwind distances similar to that observed for inline configuration, but, quantitatively differs.

3.3. Comparison of vertical spread parameter (σ_z) for single storied inline array configuration with field data

Fig.9 shows comparison of vertical spread parameter (σ_z) values obtained for single storied inline array configuration with reported field data. Experimentally obtained non-dimensionalised concentration with cubic height (H) (i.e. σ_z/H) values was plotted against downwind distances (X). Experimentally obtained values of σ_z/H for single storied buildings model of inline array configuration have been compared with field data reported by Macdonald (1998).

In comparison, experimentally observed σ_z values are below the field values reported by Macdonald (1998). They were best fitted with power law profiles. The non- dimensional concentration both for the field and wind tunnel results of single storied inline buildings configuration seems to be more or less uniform. Value of vertical spread parameters for single storied inline array configuration and field data were follow similar trend with nearly same values.

However, it was concluded that, concentration consistently larger in wind tunnel single storied inline array configuration compared field data reported by Macdonald (1998). Again, wind tunnel single storied inline array configuration data appears to be more convective and /or less diffusive than the field data. In addition concentration measured in the wind tunnel was consistently larger than field data measurement. This may be due to different roughness conditions simulated in wind tunnel from that of field. Study concluded that despite some quantitative differences, the field result and wind tunnel showed the same general trend of vertical dispersion parameter.

a) Y=8H b) Y=16H c) Y=24H

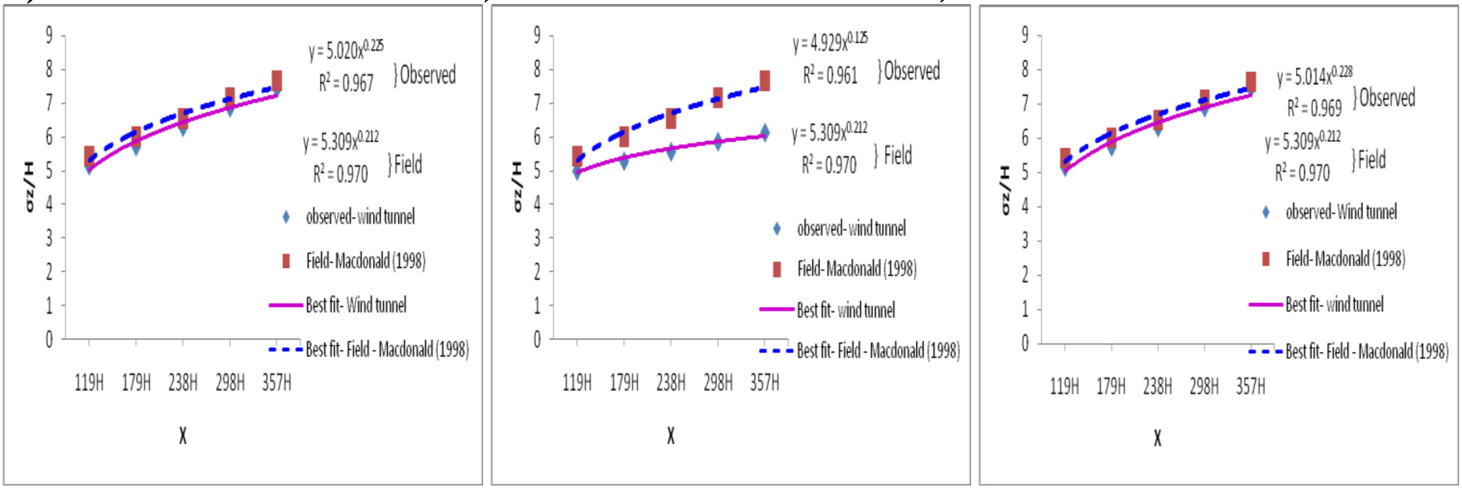

Fig. 9. Comparison of σ_z values for single storied inline array configuration with field data

3.4. Comparison of vertical spread parameter (σ_z) for single storied staggered array configuration with field data

Fig.10 shows comparison of vertical spread parameter (σ_z) values obtained for single storied staggered array configuration with reported field data. Experimentally obtained non-dimensionalised concentration with cubic height (H) (i.e. σ_z/H) values was plotted against downwind distances (X). Experimentally obtained values of σ_z/H for single storied buildings model of staggered array configuration have been compared with field data reported by Macdonald (1998).

Experimentally observed σ_z values are below the field values reported by Macdonald (1998). They were best fitted with power law profiles. The non- dimensional concentration both for the field and wind tunnel results of single storied staggered buildings configuration seems to be more or less uniform. Value of vertical spread parameters for single storied staggered array configuration and field data were follow similar trend with nearly same values.

a) Y=8H b) Y=16H c) Y=24H

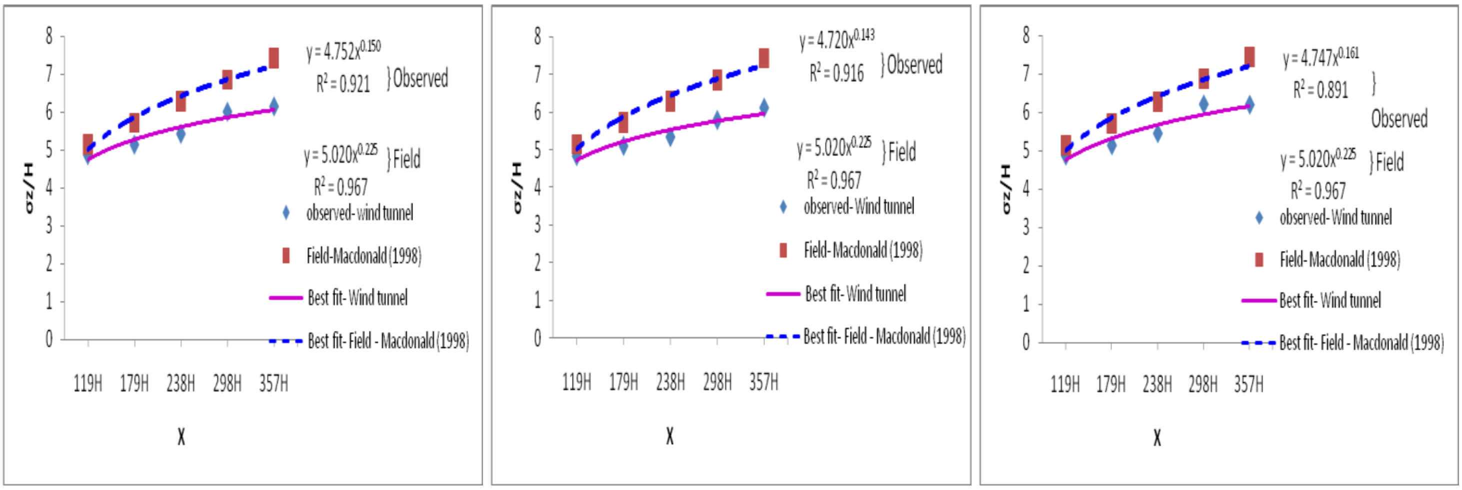

Fig. 10. Comparison of σ_z values for single storied staggered array configuration with field data

IV. CONCLUSIONS

There were significant differences between non-dimensional concentrations measured in the downwind of the obstacles in inline and staggered array. Even with quantitative differences, the inline and staggered array configuration of single storied buildings model results showed the same general trend. Downwind tracer concentration maximum near to line source (at X=119H) and it decreases with downwind distances increases (at X=357H) for single storied buildings model of inline array configuration. It was observed that, centerline concentration relatively higher for single storied buildings model staggered array configuration at all downwind distance. Vertical spread parameter (σ_z) for single storied buildings model of inline and staggered array configuration behaved in more or less similar trend with quantitative difference between centreline and either side of centerline at lateral locations. Concentration consistently larger in wind tunnel compared to field data reported by Macdonald (1998).

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