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3-Dimensional Numerical Simulation of Pollution Dispersion in an Urban Street Canyon

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ABSTRACT

Pollution dispersion mechanism in an urban street canyon has been studied using numerical simulations. Street canyon of aspect ratio "one" with perpendicular wind flow direction and pollutant line source has been modelled using ANSYS FLUENT 16.2 software code. RNG, k-ε turbulence model and species transport model were applied in this numerical study. Pollutant mass fractions at various locations of street canyon have been studied and discussed. The numerical results show significant variations of pollutant due to existence of unsteady vortex in street canyon. Pollutant concentrations were observed higher on leeward side compared to windward side. Slow mixing rate of pollutant with fresh air leads to higher pollutant accumulation in street canyon. It has been observed that pollutant concentrations were higher at pedestrian level and decreased along the height of the street canyon.

Keywords: *Street Canyon; Air Pollution Modeling; K-E Turbulence Model; Species Transport.*

1.0 Introduction

Pollution level in urban areas has increased significantly in recent decades. Population, number of vehicles, and mismanagement in development and planning are the major factors in increasing the level of pollution. Vehicle emission represents the main group of pollutants in urban areas[1]. Significant numbers of people are affected in terms of the health due to pollution. Large numbers of people spend time on street canyon as pedestrians, vendors, and passengers travelling in public and private vehicles. They are more prone to face pollution directly. A proper designing of the urban building configuration may help to ventilate street canyons and to provide continuous circulation of the fresh air. Pollutant dispersion and removal from the street canyon is governed by the wind flow. Numerical simulations using various models have been reviewed in previous studies[2].Effects of various geometrical configurations of pollutant dispersion mechanisms were studied by many researchers[3].Effects of street canyon obstacles such as traffic volume and tree planting have also been studied[4,5,6,7].In the present study pollution dispersion phenomena has been studied by simulating the wind flow and pollutant dispersion using computational fluid dynamics (CFD) technique. Objective of the study is to investigate the pollutant dispersion mechanism in an urban street canyon. Three dimensional air domain has been considered for numerical simulations. Geometrical configuration of street canyon of aspect ratio one has been taken from experimental study[8]and modelled as fluid domain has been simulated. The street canyon configuration has significant influence on the pollutant dispersion[9]. Navier stocks and species

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transport equations were solved using ANSYS FLUENT 16.2 package. Air has been considered for fluid domain material and air-acetylene mixture for pollutant. RNG, K-ε turbulence model and species transport model have been applied for simulation.

Model has been validated with two dimensional simulation[10]. Contours and plots of pollutant mass fraction have been studied and discussed at various locations of the street canyon. Outcomes of the study will be helpful for organized urban development.

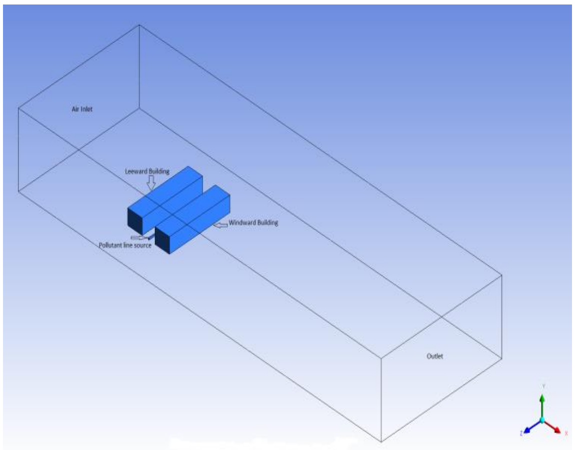
2.0 Numerical Mode

2.1 Geometrical configuration

Three Dimensional fluid domain of street canyon have been modelled and steady state simulations have been performed to study the pollutant dispersion phenomena in an urban street canyon using ANSYS FLUENT 16.2 package. Figure 1 shows a schematic of the building arrangement in a fluid domain of dimensions, 6 m X 1 m X 2 m, in x, y, and z directions respectively. Two identical cuboids of dimensions, 0.24 m X 0.21 m X 1 m, for width, height, and length respectively, have been modelled for leeward and windward buildings. One line source with two pollutant inlet planes have been created for pollutant dispersion.

The dimensions of the pollutant line source as cuboid are kept as, 0.015 m X 0.02 m X 1 m for width, height, and length respectively. A sufficient space of 4 m distance has been kept for back flow to avoid reverse flow in simulations. Building arrangement has been kept symmetrical in z direction. Fluid domain has been modelled for perpendicular wind flow in x direction. Boundaries i.e. air inlet, outlet, leeward building, windward building, and pollutant line source have been defined as shown in figure 1. Except above boundaries some other important boundaries defined are three symmetry planes, road, leeward wall, windward wall, pollutant inlet 1, and pollutant inlet 2. Air has been considered for the initial domain material.

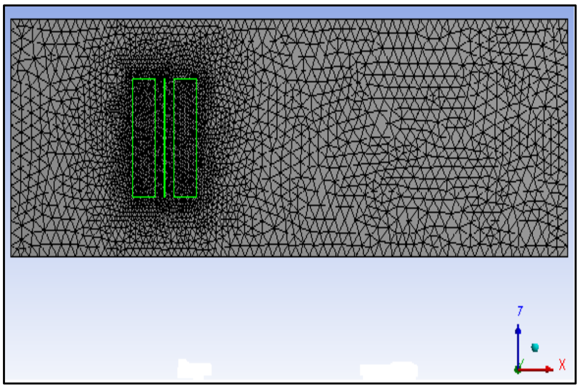
Fig 1: Three Dimensional Fluid Domain and Geometrical Configuration



2.2 Grid generation

Three dimensional grid has been generated using meshing tool of the ANSYSsoftware. The street canyon is the main region to study pollutant dispersion phenomena. Therefore high concentrations of grids have been created in street canyon and around the buildings as shown in figure 2. Tetrahedron meshing with body of influence near buildings and element sizing has been applied in grid generation properties. With fine meshing more than 2 lacs elements were generated in the domain.

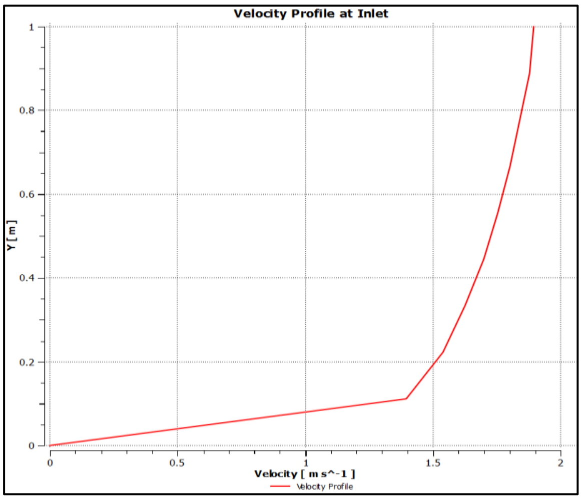
Fig 2: Bottom View of the Grid Generation of the Fluid Domain



2.3 Physics setup

Perpendicular wind flow using K-ε turbulent model with user defined function (UDF) of wind velocity as per power law equation has been applied for simulations. Air inlet mean velocity of magnitude 1.67 m/s has been taken in UDF. Velocity profile at air inlet has been shown in figure 3. Species transport model has been considered for pollutant dispersion from line source.

Fig 3: Velocity Profile at Air Inlet



Air- acetylene mixture has been taken as pollutant. Pollutant enters the fluid domain from the two pollutant inlets which are modelled as line source. Dispersion of pollutant was present on the both the side of the middle of the street canyon. Flow rate of 1lpm of the pollutant has been given.

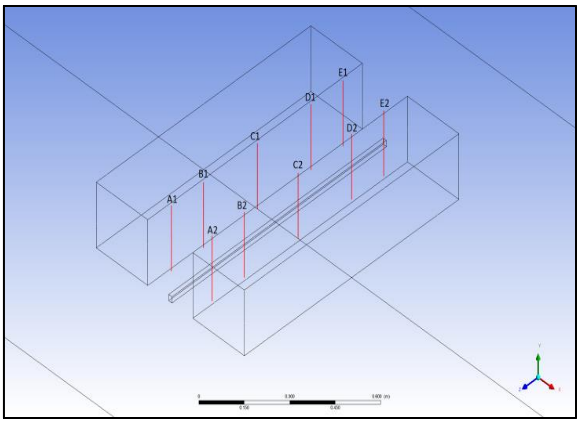
Species transport model has been applied for dispersion of the pollutants in street canyon from line source. Convergence criteria of 10^{-5} has been applied for solution.

3.0 Result Discussion

Dispersion phenomena of pollutant (acetylene mass fraction) dispersion have been discussed for an urban street canyon. Pollutant mass fractionshave been discussed as contours at different locations i.e. sections A1A2, B1B2, C1C2, D1D2, and E1E2. Contours of pollutant mass fraction on leeward wall and windward wall have also been discussed. Pollutant mass fractions along the sample lines as shown in figure 4 on leeward and windward sides have been discussed and compared. Locations of sample lines are taken as centre plane at C1C2 on XY plane.

Other planes were taken at equal distance from the centre plane on both the sides. The distances of the planes B1B2 and D1D2 were taken as 0.25 m from centre plane C1C2. Similarly the distances of the planes A1A2 and E1E2 were taken as 0.4 m from the centre plane C1C2.

Fig 4: Sample Lines on Leeward and Windward Side



3.1 Contours of pollutants

Figure 5 shows the accumulation of pollutant mass fraction at different locations of the street canyon. A significant amount of accumulated pollutant concentrations have been observed in street canyon. Pollution concentration was high on leeward wall side compared to windward wall side. The concentration of pollutants was greater at mid-section of the street canyon compared to the end sections. At ground level concentration of pollutants were measured greater than that of top of the street canyon.

Fig 5: Contours of Pollutant Mass Fraction on (i) Plane A1A2, (ii) Plane B1B2, (iii) Plane C1C2, (iv) Plane D1D2, and (v) Plane E1E2

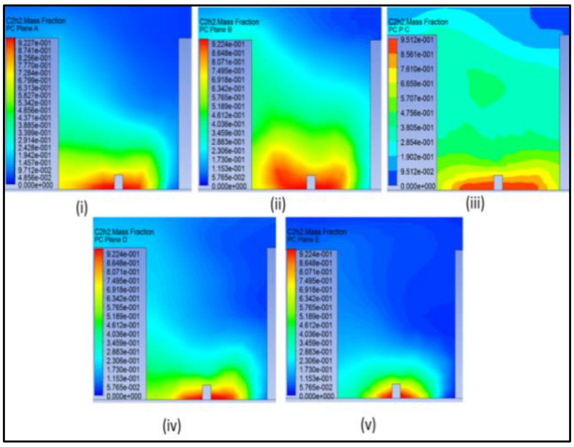


Fig 6: Pollutant Concentrations on (i) Leeward Wall and (ii) Windward Wall

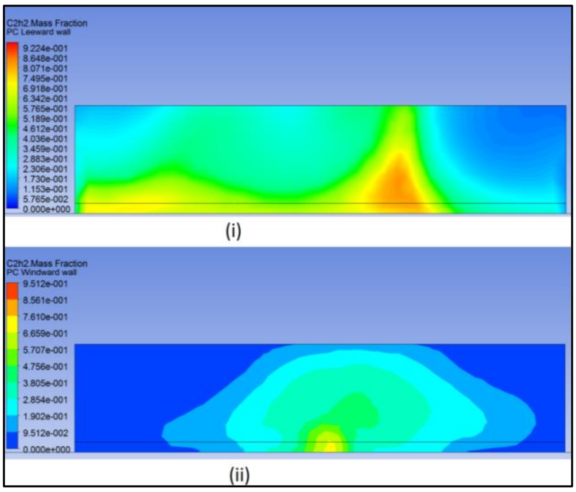


Fig 7: Streamlines of Pollutant Particles

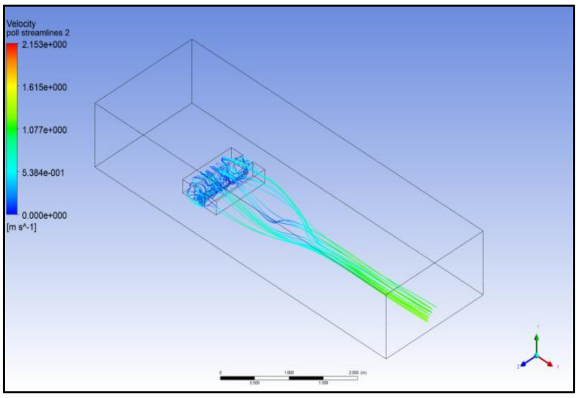


Fig 8: Volume Rendering of the Pollutant

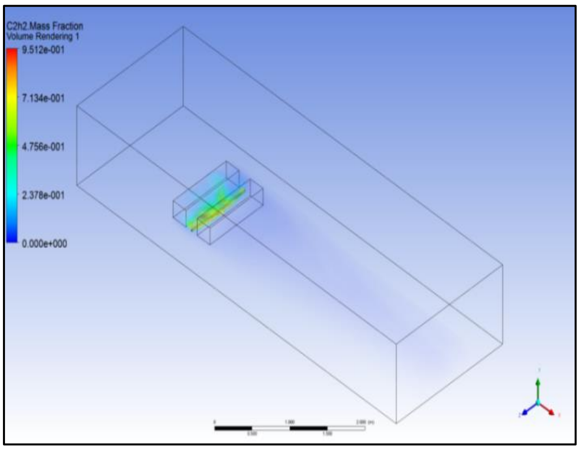


Fig 9 (i): Pollutant Mass Fraction Plots along Sample Lines on Leeward Side.

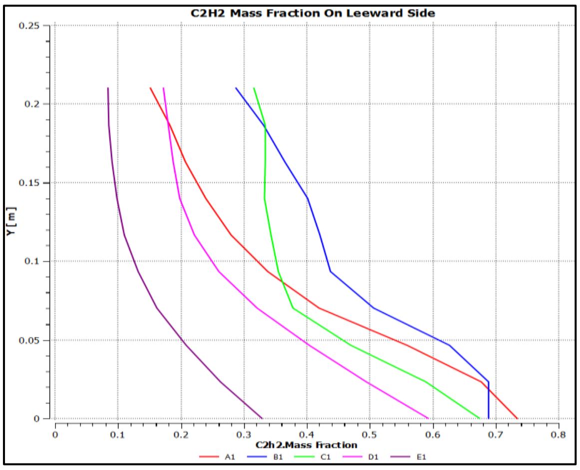


Fig 9 (ii): Pollutant Mass Fraction Plots along Sample Lines on Windward Side.

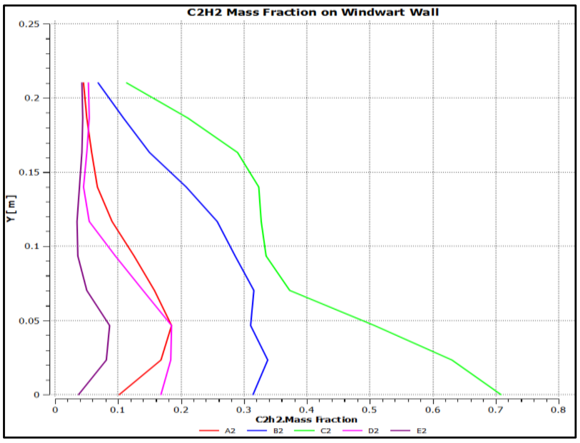


Figure 6 represents concentration of pollutants on leeward and windward walls respectively. High concentrations of pollutants were observed on leeward wall.

3.2 Stream lines and rendering of pollutant

Figure 7 represents the stream lines of the pollutant particles being removed from the street canyon. The rate of removal of the pollutant particles were observed low compared to the rate of pollutant dispersion into the street canyon, which therefore leads to accumulation of the pollutant in street canyon.

Three dimensional representation of the pollutant rendering has been shown in figure 8 for better understanding of the dispersion phenomena and pollutant accumulation inside the street canyon.

3.3 Pollutant mass fraction plots

Figure 9 (i) shows distribution of the pollutant mass fraction along the sample lines A1, B1, C1, D1, and E1 on leeward side. At pedestrian level, 0.4 m highfrom road, pollutant mass fraction varies from 0.4 to 0.65. At ground level pollutant concentration is high and decreases along height. While, Figure 9 (ii) showsdistribution of the pollutant mass fraction along sample lines A2, B2, C2, D2, and E2 on windward side.

It has been observed that pollutant concentration were low as compared to the leeward side. At pedestrian level pollutant mass fraction were ranges from 0.1 to 0.3 except on line C2.

4.0 Conclusions

Three dimensional simulationshave been carried out to find out pollutant dispersion mechanism in an urban street canyon. Computational fluid dynamics techniques arethe best low cost tool for prediction of the pollutant dispersion study in an urban street canyon. It can help in urban development and planning. RNG, K-ε turbulent model and species transport model have been applied for simulation and have predicted the results which can be validated with experimental studies. Present study shows that, accumulation of the pollutants is the major concern in street canyon mainly on leeward side. Concentrations of pollutants were found significantly high at pedestrian level. Pollutant concentration level was observed low on windward side.

This may be due the vortex wind flow in street canyon. Further study can also be done to find out the effects of the various parameters i.e. aspect ratio, wind orientation, elevated metro rail tracks, road obstacles, vehicle movements etc., on dispersion phenomena.

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