Investigation of dust dispersion in urban environment using large eddy simulation method

M.R. Shahnazari[1*], Hamid Chenarani[1], Aryan Ahmadpour[1]

[1] Mechanical Faculty, K. N. Toosi University of Technology, Tehran, Iran

ABSTRACT

Pollution and the distribution of dust in urban areas have caused a wide range of diseases. Dust is one of the environmental phenomena that has caused adverse effects on health and the environment. Contamination caused by dust of different origins is spread across a wide range of atmospheres. Our understanding of the mechanism of dust distribution and the turbulence in urban areas is very important, which helps us reduce the effects of these types of contaminants. Computational Fluid Dynamics models have been considered in this study due to the economical approach to research in the field of dust distribution. Due to the turbulence of the wind flow inside the city, we use the large eddy simulation method to model this turbulence, which is widely used in computational wind engineering. In this study, we have investigated the dust in the urban area. For this purpose, the effect of the wind direction angle and the urban environment as well as the height of the buildings on the speed distribution and dispersion of fine dust with time has been investigated in two separate computing spaces. By comparing the results between 0° and 10° angle, it has been observed that with the increase of the flow turbulence intensity angle, these turbulent characteristics lead to the dispersion and persistence of fine dust in the urban environment. By comparing the results, we conclude that by creating an angle in the urban area due to increased mixing, the amount of dust distribution in the urban area rises.

KEYWORDS

Dust, Urban area, Turbulence, Large eddy simulation

[*] Corresponding Author Email: shahnazari@kntu.ac.ir

1. Introduction

Modeling the pollution and dust dispersion in the urban area is very difficult due to the complexity of the urban geometry. Understanding the concept of pollution dispersion mechanisms in urban areas is very important and helps to reduce the effects of this type of pollution. Among the most important research methods in the study of pollution dispersion in urban areas, we can mention field observation and measurements, laboratory modeling, and computational fluid dynamics (CFD) modeling. There are several studies that investigate the pollution dispersion in urban areas with CFD models, such as using $k-\varepsilon$ model [1, 2]. Because of the huge amount of calculations, researchers use the large eddy simulation (LES) method to overcome this problem [3, 4]. The LES method solves the governing equations for large eddies directly and filters a flow field based on the scale size of the eddies. In this paper, the impact of wind angle and speed, and buildings height on the dust dispersion pattern in an urban area using the LES method investigated.

2. Governing Equations

LES method uses the filtered Navier-Stocks equations, shown below:

$$\frac{\partial \bar{u}_i}{\partial t}+\bar{u}_j\frac{\partial \bar{u}_i}{\partial x_i}=-\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i}+\upsilon\frac{\partial^2 \bar{u}_i}{\partial x_j^2}-\frac{\partial \tau_{ij}}{\partial x_j} \quad (1)$$

Instead of time averaging like in RANS, the overbar here denotes spatial filtering. Thus, the filtered velocity and pressure are and, respectively. The filtering process introduces additional tensor terms, which are referred to as SubGrid-Scale (SGS) stresses and are comparable to the Reynolds stresses that arise from Reynolds averaging:

$$\tau_{ij}=\overline{u_i u_j}-\overline{u_j u_i} \quad (2)$$

$$\tau_{ij}-\frac{1}{3}\tau_{kk}\delta_{ij}=-2\mu_t \overline{s_{ij}} \quad (3)$$

here μ_t and τ_{kk} are turbulent viscosity and isentropic section of subgrid stress. Also $\overline{s_{ij}}$ is the strain rate tensor for eddies which define as:

$$\bar{s}_{ij}=\frac{1}{2}\left(\frac{\partial \bar{u}_i}{\partial x_j}+\frac{\partial \bar{u}_j}{\partial x_i}\right) \quad (4)$$

Smagorinsky-Lilly method has been used to model μ_t. In this method, the viscosity of subgrid turbulence is modeled as $\mu_t=\rho l_s^2\left|\bar{s}\right|$ which $\left|\bar{s}\right|=\sqrt{2\bar{s}_{ij}\bar{s}_{ji}}$ and $l_s=\min\left(kd.C_s\Delta\right)$.

The lagrangian approach used for modeling particle motions. Second law of newton for each particle is:

$$\frac{d\overrightarrow{u_p}}{dt}=\frac{\left(\vec{u}_f-\vec{u}_p\right)}{\tau_r}+\left(1-\frac{1}{s}\right)\vec{g}+F \quad \textbf{(5)}$$

here the values with the subtitle "p" represent the particle, and the force F, which is just the Saffman force in this case, is the outcome of external forces acting on the particle. Also, dimensionless numbers such as Reynolds and Strouhal numbers used.

3. Numerical simulation

The problem simulated by ANSYS FLUENT. A benchmark model simulates for validation and the results compared with the Lyn's experimental results [5]. Fig. 1 illustrate the top view of domain mesh for benchmark model.

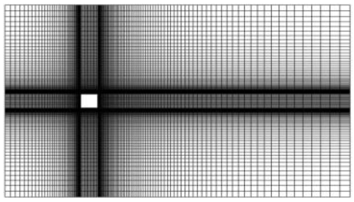

Fig. 1. structured mesh grid for benchmark model

The results show the LES method is a suitable method for simulation of turbulent flow over a body.

In order to investigate the impact of wind speed, angle, and height of buildings on dust dispersion patterns, a part of Tehran Andisheh phase two buildings with an area of 4485 square meters has been selected. (See Fig. 2.)

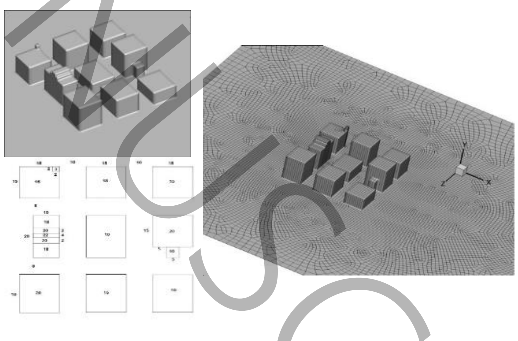

Fig. 2. Left: Urban are, Right: Unstructured domain mesh

The symmetry boundary condition is applied to the side and upper surfaces, and zero static pressure is applied to the outlet domain surface. Also, a no-slip condition is assumed for all building surfaces and the bottom of the domain. The courant number for all cells is less than 1, and to increase the accuracy of the results, first advance the solution for a few seconds without injecting the dust to eliminate the effects caused by the initial conditions.

4. Results and Discussion

To check the mesh study, the number of different mesh cells was used. A vertical line was used in the computing space, which shows the concentration graph based on the increase in height. This line is located in the first row of buildings.

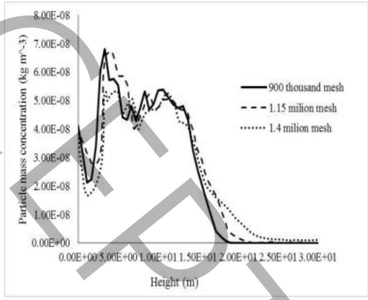

Fig. 3. Particle mass concentration for three different mesh, Urban environment with a 10-degrees angle to streamline

The number of computing cells is about 1.4 million. Two computational spaces have been used in the study, where the urban environment is placed at an angle of 0 and 10 degrees with respect to the direction of the flow. In both investigated cases, the size is equal to 5 meters per second. The dust calculated in this research is clay, which has an average diameter of 0.73 micrometers. The smallest diameter of the particle in this research is 0.2 micrometers, and the largest one is 17 micrometers, which is distributed in the computing space according to the Rosin-Remmler distribution. The density of clay used in this research is 2500 kg/m3. The particles were injected from the input screen of the computing space at a rate of 0.001 kg/s for 6 seconds. Fig. 4 depicts the dust dispersion and velocity distribution contour at t=41.3s, angle=0, and angle=10 at height of 20m.

By comparing the results obtained at different heights for two different computing spaces and the same boundary conditions, the effect of the angle of the urban environment in relation to the flow line in the dispersion of dust is fully evident, which is discussed in the next section.

5. Conclusions

By comparing the results, it was observed that the dust around and between the buildings with an angle of 10 degrees to the direction of the flow has a lot of pollution spread compared to the buildings with an angle of 0 degrees. The resulting angle has intensified the turbulence of the wind flow in and around the urban environment, and these turbulent characteristics have caused the dispersion, dilution, or persistence of fine dust in the urban environment, which can cause very unfavorable conditions for the health of residents. Therefore, it is clear that the type of arrangement of buildings has a great impact on the spread of fine dust.

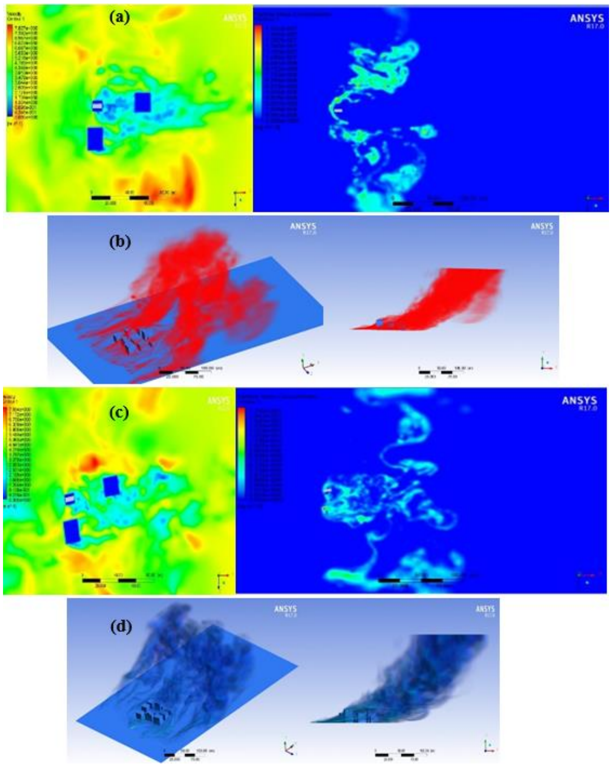

Fig. 4. a) velocity distribution contour at t=41.3s, angle=0, and height=20m, b) Dust dispersion pattern with angle=0, c) velocity distribution contour at t=41.3s, angle=10, and height=20m, d) Dust dispersion pattern with angle=10.

6. References

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