ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Dispersion and deposition of particulate matter emitted by stockpiles of granular material: a numerical approach using LES

C.L.de Morais [1], B. Furieri [1], J.M. Santos [1], E.L. Nascimento[2], J-L. Harion [3]

[1]Federal University of Espírito Santo, Vitória, Brazil, cristina.morais@aluno.ufes.br
[2]Federal Institute of Espírito Santo, Vitória, Brazil
[3]IMT Nord Europe, Douai, France

SUMMARY:
The present work investigates the atmospheric dispersion and deposition of particulate matter emitted from oblong stockpiles of granular materials using Euler-Lagrange modeling and LES to account for atmospheric turbulence. The Euler-Lagrange approach was used to solve the Eulerian equations for wind flow and the Lagrangian equations for particles. Results compared with the literature, showed that velocity profiles around the stockpile were simulated coherently. Furthermore, the particle concentration distribution in the soil showed that the pile deforms the flow in such a way that the greater emission of particles comes from the sides. Besides, along the flow direction, above the stockpile height, there are particles with velocities close to the free stream velocity. Particles with larger velocity, above free surface velocity, can be also observed in regions where the fluid is accelerated. The classical behavior of pollutant dispersion is observed: the plume of particles spreads vertically, and laterally, showing that the proposed modeling has a good physical foundation.

Keywords: Euler-Lagrange, particulate matter, wind erosion.

1. INTRODUCTION

The presence of particulate matter (PM) in the atmosphere can cause direct damage to the environment and to human health. Among industrial sources, storage of granular materials in open yards can be a significant source of PM of different granulometry. The stockpiles are exposed to wind erosion causing emission that carry particles to its surroundings and beyond depending on meteorological conditions (Wang et al., 2022). Many authors have numerically obtained good result of the flow field solving the fundamental transport equations for turbulent flow using the Reynolds Averaged Navier-Stocks (RANS) models (Derakhshani et al., 2013; Ferreira et al., 2020; Furieri et al., 2012). However, it is well documented in the literature (Brito et al., 2020) that Large Eddy Simulation (LES) gives better results compared to other turbulence models. In addition, most of the studies consider the stockpile as a solid surface and the flow field without the presence of particles. Multiphase flows, as particles dispersion and deposition, can be modelled by Euler-Lagrange (E-L) approach. In this case, the wind is considered a continuous phase while particles are viewed as a discrete phase allowing them to be individually tracked by a force balance analysis. In this context, this work aims to investigate the dispersion and deposition of particulate matter of different sizes emitted from a stockpile using the E-L approach and LES to account turbulence effects.

2. NUMERICAL MODELING AND SOLUTION

2.1. Eulerian modelling of the atmospheric turbulent flow

The Large Eddy Simulation (LES) model consists of applying, on the governing fluid flow equations, a spatial filtering operation to separate the larger and smaller eddies. Continuity and Navier-Stokes time-dependent flow equations after applying a filter were used. The equations and more detailed information can be found in Versteeg & Malalasekera (2007). There are many models to describe the SGS viscosity, but in the present work the Wall-Adapting Local Eddy-Viscosity (WALE) model is used.

2.2. Lagrangin modelling of the particle flow

The Lagrangian flow of the dispersed phase is governed by particle position and *momentum* equations, respectively:

$$u_{pi} = \frac{dx_{pi}}{dt} \tag{3}$$

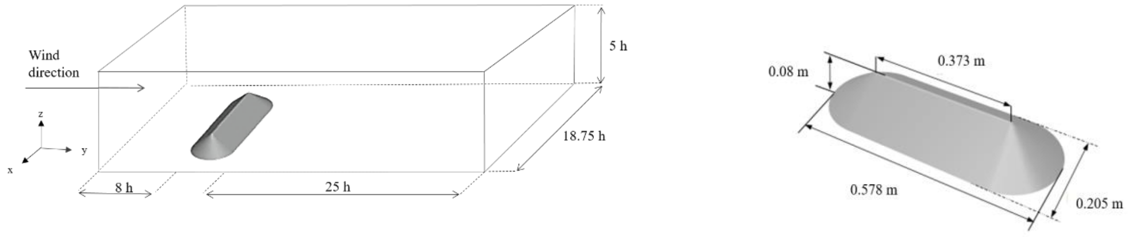
where x_p is the particle position [m], u_p is the particle velocity vector [m/s].

$$\frac{du_{pi}}{dt} = \sum_{i=1}^{n} \frac{F_{pi}}{m_{pi}} + \left(1 - \frac{m_{pi}}{m_f}\right) g \tag{4}$$

where, i is the particle index within a population of n particles, x_{pi} [m], u_{pi} [m/s], and m_{pi} [kg] are the i^{th}particle position, velocity and mass, respectively, t [s] is time; m_L [kg] is the mass of fluid displaced by the particle and g [m/s²] represents gravitational acceleration. In the present work, the only contributions to F_p came from the total drag and added mass force.

2.1. Computational domain and mesh

The computational domain, the stockpile model and its dimensions are showed in Fig. 1. Fig. 2 shows the mesh details. The three-dimensional equations of mass and momentum conservation were solved using the software Ansys Fluent 14.0®.



(a) (b)

Figure 1. (a) computational domain and its dimensions as a function of the height h (0.08 m) of the stockpile and (b) oblong stockpile dimensions.

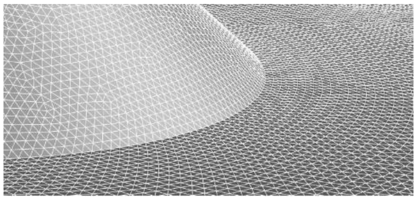


Figure 2. Mesh details in stockpile and ground walls.

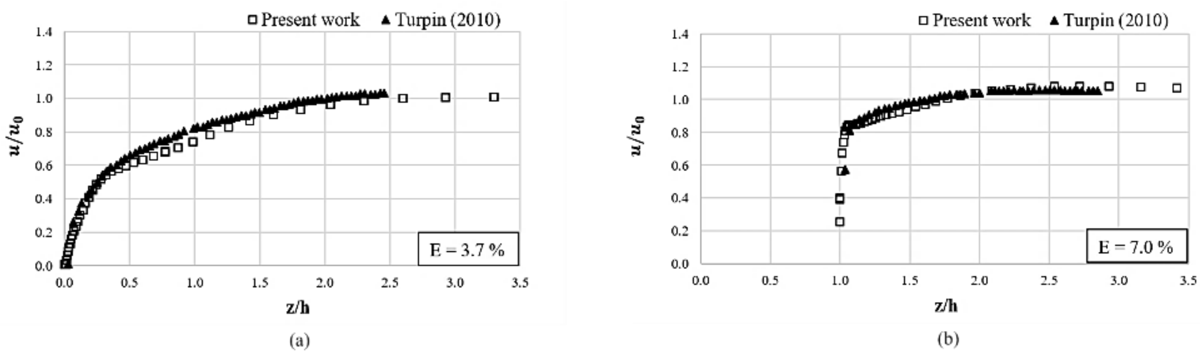
2.2. Boundary conditions

The inlet condition was a mass flow rate value corresponding to a velocity of 5.5 m/s. For the outlet it was assumed that all flow variables, except pressure, have a zero normal gradient. For the upper wall was imposed symmetry condition. Smooth walls with no-slip conditions were set at lateral domain, ground, and stockpile walls. For dispersion modeling by the Lagrangian approach it was necessary to calculate and implement in the software a natural decay of the emission rate (Furieri et al, 2013) of the particles that were inserted in the domain through the stockpile surface over the time.

3. RESULTS

3.1. Comparative analysis of the vertical and horizontal velocity profiles

Vertical and horizontal velocity profiles obtained numerically were compared with experimental results of Turpin (2010) in order to validate the simulations. Two of them are shown in Fig. 3. Observing Figure **3**, the numerical results satisfactorily reproduce the experimental velocity data around the stockpile with relative errors of 3.7% and 7.0%.



(a) (b)

Figure 3. Vertical velocity profiles (a) 1, (b) 2. Profiles numbering according to Figure 5. Highlighted are the relative errors (E).

3.2. Particles dispersion and deposition evaluation

Fig. 4 shows the instantaneous particles concentration distribution on the ground surface. The stockpile sides are responsible for the highest particles emissions, and this large number of particles are dragged and the same values are observed in the plume along the entire domain.

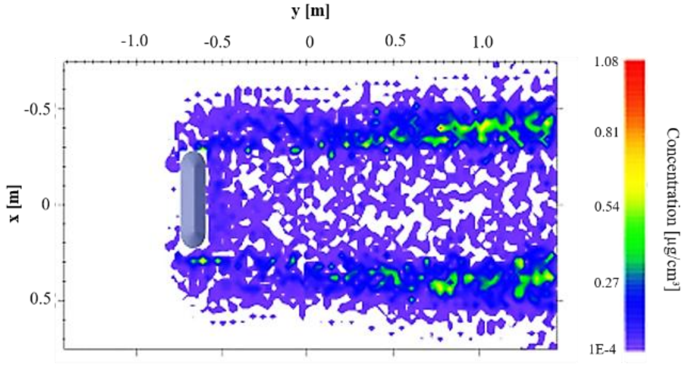


Figure 4. Instantaneous concentration distribution on the ground surface (z = 0).

Another interesting analysis can be made if we look on the result of dimensionless instantaneous particles velocity as shown in Fig. 5 in isometric (a) and top (b) view. It is possible to see particles at the pile surface with zero velocity marking regions of injection, as expected. Along the flow direction, above the stockpile height, there are particles with velocities close to the free stream velocity ($u/u_0 = 1$). Particles with larger velocity, above free surface velocity, can be also observed in regions where the fluid is accelerated. Again, the classical behavior of pollutant dispersion is observed: the plume of particles spreads vertically, Fig. 5(a), and laterally, Fig. 5(b).

Figure 5. Dimensionless instantaneous particles velocity. (a) isometric and (b) top view.

REFERENCES

Brito, P. M., Ferreira, A. D., Thiis, T., & Sousa, A. C. M. (2020). Geomorphology Prediction of erosion intermittency using Large Eddy Simulation. *Geomorphology*, *364*, 107179.

Derakhshani, S. M., Schott, D. L., & Lodewijks, G. (2013). Dust emission modelling around a stockpile by using computational fluid dynamics and discrete element method. *AIP Conference Proceedings*, *1542*, 1055–1058.

Ferreira, M. C. S., Furieri, B., de Morais, C. L., Stocco, J. F., Reis Jr, N. C., Harion, J.-L., & Santos, J. . (2020). Experimental and numerical investigation of building effects on wind erosion of a granular material stockpile. *Environmental Science and Pollution Research*, *27*, 14.

Furieri, B., Russeil, S., Harion, J. L., Turpin, C., & Santos, J. M. (2012). Experimental surface flow visualization and numerical investigation of flow structure around an oblong stockpile. *Environmental Fluid Mechanics*, *12*(6), 533–553. https://doi.org/10.1007/s10652-012-9249-0

Furieri, B., Russeil, S., Santos, J. M., & Harion, J. L. (2013). Effects of non-erodible particles on aeolian erosion: Wind-tunnel simulations of a sand oblong storage pile. *Atmospheric Environment*, *79*, 672–680.

Versteeg, H., & Malalasekera, W. (2007). An Introduction to Computational Fluid Dynamics: The Finite Volume Method (2nd éd., Vol. M). (S.l.) : Pearson. https://doi.org/10.2514/1.22547

Turpin, C., & Harion, J. L. (2010). Effect of the topography of an industrial site on dust emissions from open storage yards. *Environmental Fluid Mechanics*, *10*(6), 677–690. https://doi.org/10.1007/s10652-010-9170-3

Wang, Z., Zhou, W., Jiskani, I. M., Ding, X., & Luo, H. (2022). Dust pollution in cold region Surface Mines and its prevention and control. *Environmental Pollution*, *292*(PA), 118293.