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ScientEvents
ProScience 1 (2014) 429-434
ProScience

Conference Proceedings
1st International Conference on Atmospheric Dust - DUST2014

Dust generation in transfer chutes: a new method to model dust flow in CFD

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Abstract

This paper presents a method for the analysis of dust transport around bulk material handling systems (BMHS), including systems such conveyor transfer chutes or material stockpiles. The aim is to allow for the comparison of passive dust emission controls. The process utilises the Discrete Element Method (DEM) to determine properties of the bulk material stream which are then passed to a Computational Fluid Dynamics (CFD) simulation to allow for the dust transport to be determined. Depending on the case the DEM simulations may be negated and CFD used alone. Three example CFD simulations were conducted to demonstrate how passive dust emission controls can be compared using this method.

Keywords: Transfer chute; dust transport CFD; DEM; material handling.

1. Introduction

Dust generation, emission and transport are topics that have gained significant interest in recent times due to the growing awareness and concerns of the impact of fugitive dust emissions on the environment and on people's health. These concerns have resulted in strict guidelines on industry being imposed by government and non-government organisations; for the protection of the environment and people in the vicinity of industrial dust emission sources. The restrictions require industry to monitor and report on the levels of dust emission from their sites and to ensure that the levels do not exceed the limits to avoid incurring heavy fines. Dust emission controls can be either active or passive systems. Active systems are often expensive and require a lot of maintenance. Passive systems

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ISSN: 2283-5954
Selection and peer-review under responsibility of DUST2014 Scientific Committee
DOI:10.14644/dust.2014.070

require little to no maintenance or ongoing costs; these include shelter belts or better design of conveyor transfer points to minimize dust generation and air entrainment. In order to choose the most efficient means to control dust from an industrial site or process there is a need to compare different material handling system designs in the early design stages for their relative dust generation and transport.

A number of computational fluid dynamics (CFD) studies have been conducted in regards to dust emission from stockpile surfaces; these use the surface stresses and a dust emission model to determine dust emission rates or potentials such as that of Turpin & Harion (2009). Also, CFD studies have been conducted on dust emission from transfer chutes such as that of Chen et al. (2012) who used the two-fluid model to model the bulk solids material flowing through transfer chute; dust emission was inferred from the air velocity at the outlet. Katterfeld et al. (2010) also simulated flow through transfer chutes with CFD to determine dust emission rates; this study also only inferred a dust emission rate. The above studies all determine dust emission rates (or potentials) from the sources but do not look at the dust transport.

2. Dust Generation Models (DGM)

Potatpov & Donohue (2013) published a comparative DEM study on material breakage in two different transfer chutes using a breakage model developed by Vogel & Peukert (2005). The simulations showed clear differences in the breakages rates and zones of the two transfer chute designs. Due to the nature of DEM and time stepping requirements based on particle sizes, any particles below a particular threshold are treated as lost material. This lost material includes all dust particles; as such a fraction of this variable can be used as a dust source term in the CFD simulation for the dust transport. Alternatively any DEM dust generation models developed in the future can be implemented and then used in this process.

3. Dust Transport Modelling

In terms of modelling dust transport DEM simulations are not feasible due to the intense computational expenses; as the simulation time step is proportional to particle diameter. The transport is better suited to computational fluid dynamics (CFD) which solves the transport equations over a control volume to determine the flux of fluids/species travelling through the volume. The main assumptions that will be applied for this process are that the dust particles are in relatively low concentrations, and they are sufficiently small to have negligible influence on the fluid flow. These assumptions will allow for the dust transport to be modelled using a single phase fluid simulation as opposed to the more complicated two-way coupled multiphase simulations; as there are numerous models and parameters that need to be set accurately as found by Chen & Wheeler (2013).

3.1 Dust transport

In the CFD simulations the dust will be modelled a number of ways, the first and most simple being the use of a passive scalar; which is a variable that is directly transported by the fluid flow but does not affect it. This is an assumption that may be made for very fine dust particles with Stokes numbers much less than one; with the Stokes number being a measure of how well a particle follows the fluid’s stream lines. For particles with larger

Stokes numbers this assumption will not hold and the particles inertia should be accounted for using a one-way coupled discrete Euleranian or Lagrangian multiphase simulation (DEMP, DLMP). DEMP and DLMP simulations solve for the primary fluid phase, and then solve for the transport of the secondary phase; the secondary phase does not affect the primary phase and as such still avoids multiphase interface transfer models.

3.2 Indirect – DEM to CFD

At present there are not many options available for fully coupled CFD-DEM solvers, as there are countless options available for both standalone CFD and DEM it is crucial to develop a process that can be used with what is currently available. This requires first a DEM simulation to be run to determine setup parameters for the CFD simulation.

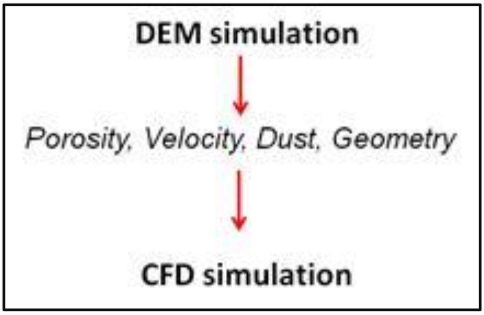

Fig. 1. Dust transport simulation process.

The process requires firstly the DEM simulation to be undertaken to extract variables such as porosity, velocity (of the particles), dust generation rates and geometry (of the material stream). This information can then be used to setup a CFD simulation where the material stream is treated as a solid wall; with velocity, air entrainment/expulsion determined from porosity and dust generation rates. The CFD simulation will then be run with the dust input as either a passive scalar, or as a one-way coupled secondary phase to determine transport.

4. Results

To illustrate the process an example simulation has been conducted for free falling material. For the purpose of this simulation no DEM simulation was done as a priori, instead the material stream velocity was determined using dynamics of a freefalling material stream. Air entrainment into the material stream was calculated using an air entrainment model; equation 1. Generated dust was input from a small annulus region where entrained air was been expelled, the dust in this case is simply a passive scalar.

$$\frac{dQ}{dh} = \frac{A\alpha_{s1}\sqrt{2g}}{2h} \tag{1}$$

Where, A is the x-sectional area of the material stream, alpha is the solid volume fraction at the beginning, g is gravity and h is the distance the stream has fallen.

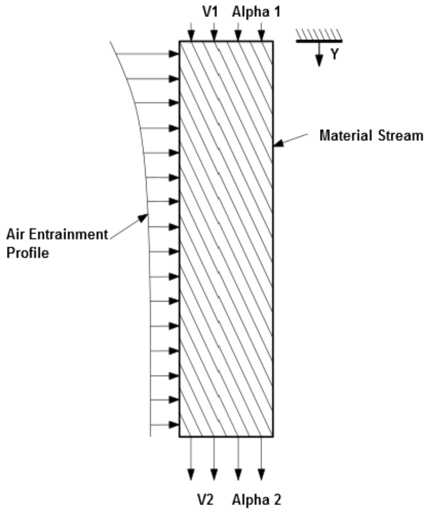

Fig. 2. Schematic diagram of air entrainment model.

Fig. 2 shows a diagrammatic representation of the air entrainment model used. Equation 1 was formulated for a freefalling material stream, and as such the change in velocity is covered by the height. This model could be used with velocity and porosity data attained by other analytical means or DEM simulations.

Fig. 3 shows the velocity profile through the centre plane, where there is a large slow velocity region for the case with the porous fence. This low velocity region will help to settle out dust particles instead of transporting them directly downstream.

Table 1 shows the centroid position for each case; global coordinate system being on the ground at the centre of the material pile, allowing for the comparison of the centre of the "spread" of the entrained air. Wall shear and turbulent kinetic energy on the stockpile surface have also been included as they are also attributed to surface dust emission, and it shows that the porous fence is the superior alternative for reducing surface emission which has been found in the experiment conducted by Yeh et al. (2010). The maximum and average residence time have been shown for the streamlines emanating from the air expulsion region (where the dust will come from) to show the difference in speed of the overall streamlines, which would have a direct correlation with the dust transport.

Table 1. Centroid of cloud, Wall Shear & Turbulent Kinetic Energy on Stockpile Surface.

Case	**Centroid [m]**	**Wall Shear [Pa]**	**TKE [m^2s^-2]**
No Control	[10.4, 3.5, 10.7]	4.96e-4	1.01e-3
Porous Fence	[6.6, 3.4, 6.0]	2.51e-4	5.02e-4
Solid Fence	[3.3, 3.0, 2.5]	3.24e-4	7.91e-4

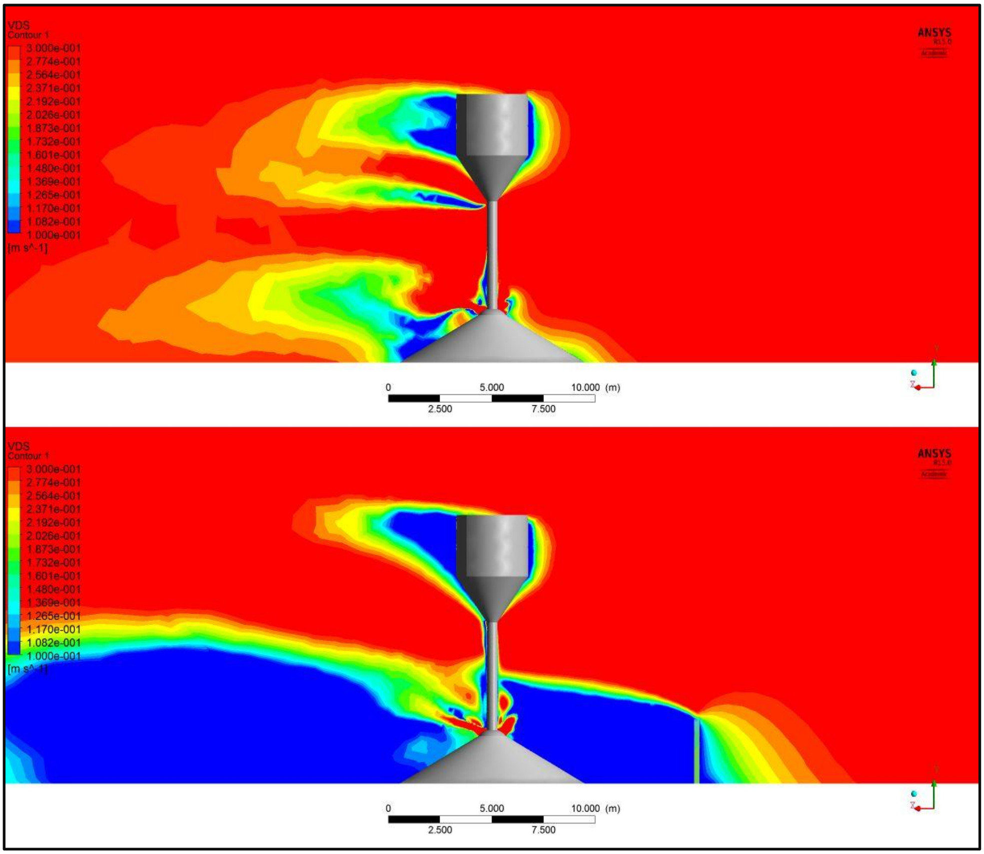

Fig. 3. Downstream velocity on centre plane. Top: stockpile no control. Bottom: stockpile with porous wind break.

5. Conclusion

This study aimed to use simulation techniques in both DEM and CFD to allow for the simulation of dust generation, emission and transport from bulk material handling systems. The CFD examples showed how a previous analytical solution or DEM simulation can be used as a priori to setup the CFD simulation to allow for the modelling of dust emission and transport. Future studies, will aim to be done on an actual transfer chute simulation and validated experimentally, as well as implementing similar techniques in a fully coupled CFD-DEM simulation to avoid the intermediate post processing steps.

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