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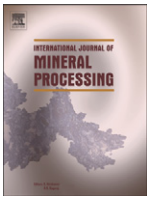

On the analysis of a coarse particle free falling material stream

A.A. Esmaili [a,*], T.J. Donohue [b], C.A. Wheeler [a], W.M. McBride [a], A.W. Roberts [b]

[a] School of Engineering, University of Newcastle, NSW 2308, Australia
[b] TUNRA Bulk Solids, University of Newcastle, NSW 2308, Australia

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ABSTRACT

In many industries across the world, the topic of dust control is a major concern. Within the bulk material handling process the action of material free fall is generally unavoidable. In this case, the adjacent air surrounding the free falling stream is induced into the stream of bulk material as the particles naturally dilate, which results in generation of dust upon subsequent compaction of the stream. Obtaining a better understanding of the way air is induced into the stream of bulk material, and the quantity of the induced air, will assist in the design of more efficient dust control systems.

In this paper the interaction between the particles and the air is reviewed. A series of computer simulations and physical experiments have been carried out. The particle image velocimetry (PIV) technique has been employed to measure the fluid velocity within a free falling stream of coarse material. Each experiment was also simulated using Ansys CFX. Particle and air velocities as well as air entrainment readings from simulation have been compared with experimental measurements and theoretical formulas. The experimental programme was designed and conducted to classify the effect of particle diameter and particle density independently. This paper presents several distinct sections that detail the experimental and simulation results as well as a comparison of these two methods while also including a discussion of existing theories.

1. Introduction

Amongst different industries and applications, bulk material handling is known as a major cause of fugitive dust generation. Quantifying and controlling dust pollution within many industries is globally an increasing focal point as more stringent Occupational Health, Safety and Environment (OHSE) regulations are specifying significantly lower acceptable dust levels across all industries. Additionally, higher dust levels in work environments require equipment with higher dust ingress protection requiring more advanced sealing and eventually costs.

The most common dust control methods used in industry rely on 'active' systems, where external energy or suppressants are required. Water utilisation is one of the most common dust control mitigation techniques. Not only is water consumption significant in terms of energy for pumps etc., but in arid countries like Australia the use of potable water for dust suppression reduces the availability for agriculture and residential uses. As an example, a medium sized coal mine in NSW uses approximately 85×10^6 l of water per annum. Furthermore, adding moisture to the bulk solid can change the cohesive strength, which may result in flow blockages and therefore increased operating costs.

Within the free falling process, the adjacent air surrounding a free falling stream of bulk material is induced into the stream and upon compaction of the stream may be exhausted into the atmosphere (along with dust particles). To this end, a better understanding of the way air is induced into the stream of bulk material and the quantity of the entrained air will assist in the design of a more efficient dust control system (Liu et al., 2007).

The air entrainment pattern of a free falling stream of bulk material can be influenced by bulk material properties such as particle size and density as well as operating conditions such as drop height, particle mass flow rate and the other environmental factors (Cooper and Arnold, 1995; Wypych et al., 2005). As a result of these observations,

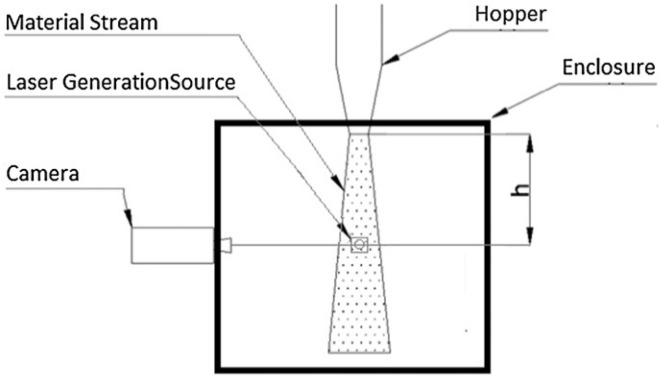

Fig. 1. PIV setup schematic.

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[*] Corresponding author.
E-mail address: Amir.Esmaili@uon.edu.au (A.A. Esmaili).

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Table 1
Summary of materials.

Material	Solid density (kg/m^3)	Bulk density (kg/m^3)	Average particle size (mm)	26 mm hopper outlet mass flow rate (kg/s)
3 mm plastic pellets	870	522	3.0	0.09
3 mm glass beads	2450	1445	3.0	0.34
6 mm glass beads	2450	1331	6.0	0.26

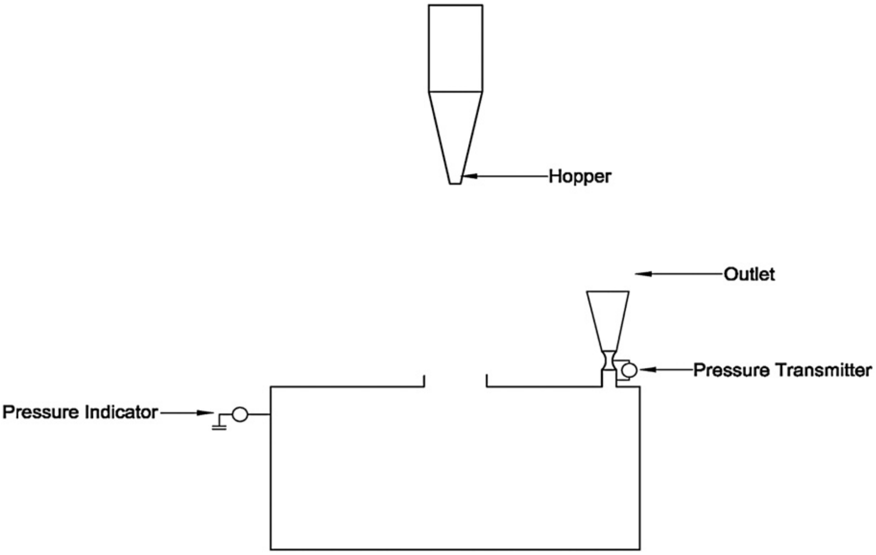

Fig. 2. Schematic view of experimental setup.

it has been acknowledged that there are other parameters which can influence the dust generation pattern of bulk material streams. These parameters are categorized under the 'passive' dust control topic in which no external energy sources are used. Passive dust control techniques have received substantial attention as either a complementary option to improve the efficiency of active systems or to be used as a viable alternative (Donohue et al., 2012; Chen et al., 2012).

There is limited published research on the diameter of a falling stream. Ansart et al. (2009) investigated the diameter of a falling stream by employing PIV and concluded that by decreasing the particle size the plume diameter increases. However, this work has only considered fine particles from 34 to 97 μm. In a more recent study, Ansart et al. (2011) studied the impact of drop height on diameter and intensity of fine particle stream by utilising an image analysis technique. This work concluded that by increasing the drop height, the stream diameter increases, and as the result of the intensity at the stream core decreases, with this finding being reproduced in the work of Esmaili et al. (2013). A coarse particle stream diameter study was conducted by Esmaili et al. (2013) in which a method for free falling stream diameter measurement using a high-speed camera along with an image analysis technique in Matlab was proposed.

The first comprehensive published work for air entrainment calculation into a stream of freefalling granular material was undertaken by Hemeon (1963). He studied the induced air based on the work performed by a single particle. The induced air volumetric flow rate, Q_{ind} is given by Eq. (1) (converted to SI units by Wypych et al. (2005)):

$$Q_{ind} = \sqrt[3]{\frac{0.66g\,\dot{m}\,(hA)^2}{d_p\rho_p}} \tag{1}$$

where $\dot{m}$ is the mass flow rate of bulk material, h is the drop height of material, A is the cross-sectional area of the falling stream of material, d_p is the particle diameter, g is the gravitational constant and ρ_p is the solids density of the particle. The cross-sectional area of the falling stream is the specific parameter of concern in this work.

Ansart et al. (2011), after reviewing Hemoen's work (Hemeon, 1963) and comparing it with other theories and experimental results, concluded that this theory grossly overestimated the amount of the entrained air. Moreover, Ogata et al. (2001) have shown that the velocity of a stream of freefalling bulk material is higher than the velocity of a single particle, which is not addressed in Hemeon's model. Cooper and Arnold published a theory for coarse particles which is based on volume conservation theory. One of the main assumptions in this work was that

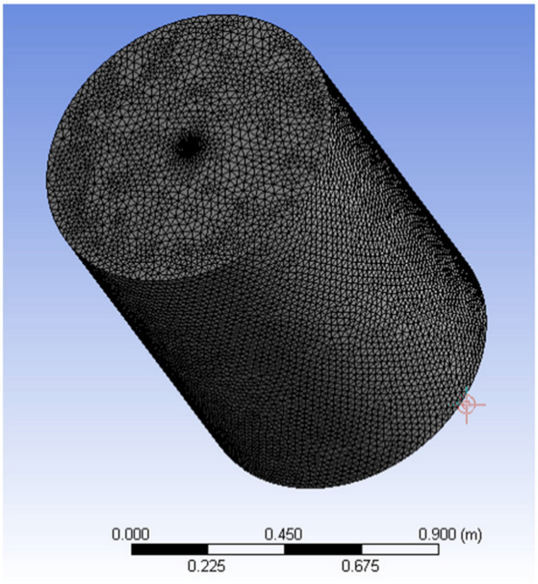

Fig. 3. CFD geometry used for benchmark simulation (cylinder shape).