Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Dispersion of Irregular Particles during Free Fall

To cite this article: A.F.M. Fadzir *et al* 2020 *J. Phys.: Conf. Ser.* **1532** 012010

Dispersion of Irregular Particles during Free Fall

A.F.M. Fadzir[1], S.I. Rani[1*], J. Gimbun[2]
[1]Faculty of Chemical Engineering Technology, TATI University College, 24000 Kemaman Terengganu, Malaysia. Tel./Fax +6-09-8601000/+6-09-8635863, Email: anisfarhan610@gmail.com, ilyani@tatiuc.edu.my (corresponding author).
[2]Center of Excellence for Advanced Research in Fluid Flow (CARIFF), Universiti Malaysia Pahang, 26300, Malaysia. Tel./Fax +6-09-549 3227 /+6-09-549 3250, Email: jolius@ump.edu.my

Abstract. This paper describes an experimental set up to examine the relationship between powder properties on powder flow pattern during filling operation. For this purpose, the free fall velocities of four types of agricultural dusts (i.e. castor sugar, oat, semolina and tea powder) in a rectangular enclosure were captured using a Particle Image Velocimetry (PIV). The result reveals that oat powder portrayed greater cloud dispersion due to its flaky shape and a lower bulk density. The characteristics of oat powder allowed more air to be dragged into the particle stream and forced the particle to be dispersed and suspended in air due to drag force and terminal velocity. The result presented here may facilitate improvements in dust control and measures in powder industries.

1. Introduction

Agricultural powders are essential commodities in food industries. In industries, powders often undergo a lot of processes such as mixing, milling, packaging and storage. These operations require the powders to move and flow under desired conditions, and, yet, several challenges remain in the handling, transporting and storing since bulk materials containing fractions of fines. Such fines generate dust emissions that can cause a number of problems in industry such as dust explosions besides may induce health risks for operator's and facilities hygiene. Powders behave differently under varying conditions. The behaviour of a powder is influenced by its characteristics, powder handling and processing conditions. The particle is often assumed spherical whereby their settling is dictated by simple drag phenomena. However, food powder such as cereal is not spherical, in fact they are flaky. Dust dispersion of flaky particles in silo is not yet fully understood and hence this is the aim of the current work.

A considerable amount of literature has been published on handling spherical particles. However, in industrial applications, solid particles are not always in spherical shape. The particles vary in shape, size, and spatial orientation, which cause particles to free fall at different rates, such as the works [1]. In 1982, Bhatty et al. studied particle behavior of suspensions at low concentrations with focus on free settling and cluster forming regions. They found non-spherical particles showed rotation in free settling while larger particles with higher settling velocities created vortices in their wake during sedimentation. Smaller particles would move into the vortex wake triggered by larger particles and forming temporary clusters. The cluster would disrupt if the settling velocity of the larger particle and the cluster in its vortex differed too much since it could not be sustained by the vortex [2].

Due to the hindrance effect, the sedimentation rate of a single particle in free settling is always higher than the sedimentation rate of the clusters. Higher terminal velocity of clusters is found because of the decreased drag on individual particles. At higher concentrations, the hindered effect resulting from an increase in concentration is due to various factors such as a decrease in the open cross section for the upward flow of the dispersion media, which results in an increased fluid approach velocity and apparent viscosity; and a decrease in gravitational forces due to a decrease in the difference in apparent specific gravity between the particles and the medium [3]. Dollimore and Mcbride carried out numerical study using Dollimore-Mcbride equation and found out that suspensions exhibiting hindered settling behavior provided information on particle size, particle packing, and sedimentation mechanisms [4]. Gu carried out numerical study to predict the flowrate of bulk solids from conical mass flow bins.

Zhu et al. raised several concerns about particulate system and emphasised on the microdynamics including packing/flow structure and particle–particle, particle–fluid and particle–wall interaction forces [5]. The hindered settling behaviour of pharmaceutical suspension was investigated by Jain [6]. In another study, Waduge et al. utilised a single camera and a laser to capture the wood dust concentration in different areas of the silo [6]. Rani et al. performed numerical analysis of dust release from bulk solid during handling using Computational Fluid Dynamics (CFD) [7]. With the same objective, Daniel et al. conducted numerical study using coupled Discrete Element Method (DEM)/Computational Fluid Dynamics (CFD) [8]. In summary, many interesting results indicating the hindered settling behaviour have been reported. In particular the effect of particle properties on powder flowability remains unexplored.

2. Methodology

Four types of agricultural powder (castor sugar, semolina, tea and oat) were loaded into a hopper with square opening outlet of 65°, then discharged into an enclosure by a screw conveyor positioned under it. The powders were fed centrally into a square Perspex test enclosures of 60 cm by 60 cm cross section and a height of 100 cm (Figure 1) at 2 m/s conveying velocity.

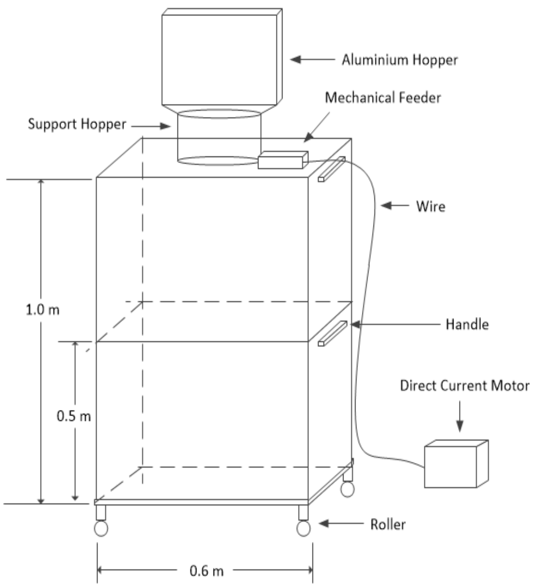

Figure 1: Experimental arrangement

A Particle Image Velocimetry (PIV) system is used to measure the particle velocity field in three separated parts (Region A, Region B and Region C) as shown in Figure 2. The material used in the experiment are summarised in Table 1, and the shape of particles are given in Figure 3, which were taken by Scanning Electron Microscope (SEM).

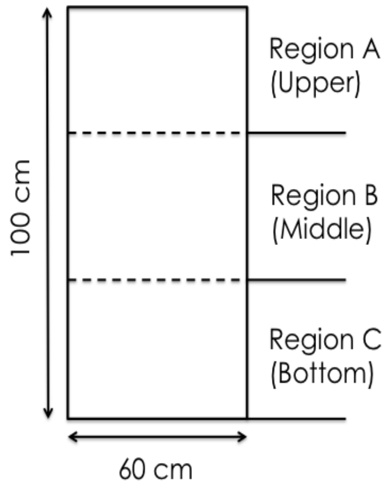

Figure 2: Regions for PIV analysis

The PIV system consists a CCD (Charge Coupled Device) camera with 1260 × 1024 pixels resolution with high power double-pulsed Nd:YAG laser. The PIV is located in front of the experimental rig to capture the particle flow. A green laser light Nd:YAG (wavelength: 532nm, energy/pulse: 30mJ, pulse duration: 4ns and frequency: 15Hz) generated pulsed laser sheet and illucidates a plane light at the centre of particle flow and the particle flow is recorded by CCD camera. The green laser light acts as a photographic flash for the digital camera. The CCD camera is capable to deliver 50 images per second of recording with the resolution of 1260 × 1024 pixels. Calibration is undertaken before capturing the flow regime.

Table 1: Powder properties

Particles	**Shape**	**Bulk Density (kg/m^3)**	**Average Size (μm)**
Castor Sugar	Crystalline	891.2	336.3
Oat	Flaky	273.0	423.4
Semolina	Aggregated	734.1	598.1
Tea	Irregular	416.4	267.1

Journal of Physics: Conference Series **1532** (2020) 012010 doi:10.1088/1742-6596/1532/1/012010

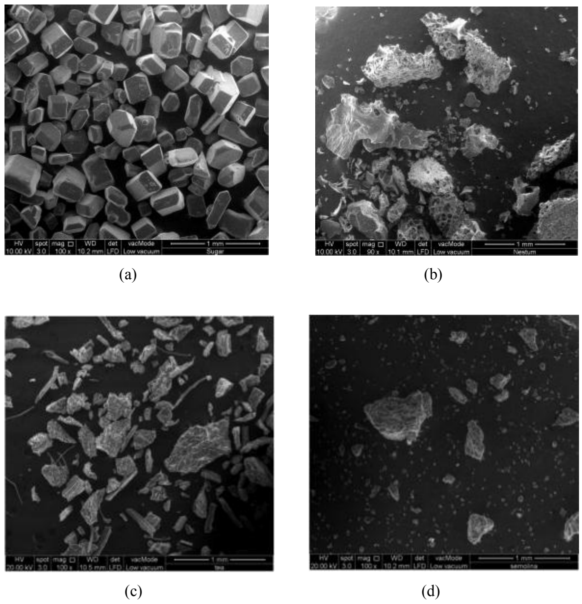

Figure 3: SEM image of particles (a) Castor sugar (b) Oat (c) tea (d) semolina

3. Results and Discussion

The image captured by PIV is portrayed in Figure 4. The finding of the present study suggested that the particle dispersion during silo filling is strongly dependent on powder characteristics. As illustrated in Figure 4 (b), the dispersion of oat powder generates greater cloud dispersion due to the lowest bulk density and flaky shape, although the particles have bigger average size. Low bulk density induced more air from the surrounding into the particle stream and increased dust emission to the surrounding. Highest dispersion of flaky particles indicates that the drag forces of particles are equal to the gravitational pull on the particles. Hence, the particles are continues falling at a constant speed, so-called the terminal velocity and consequently generate more airborne-dust in the surrounding.

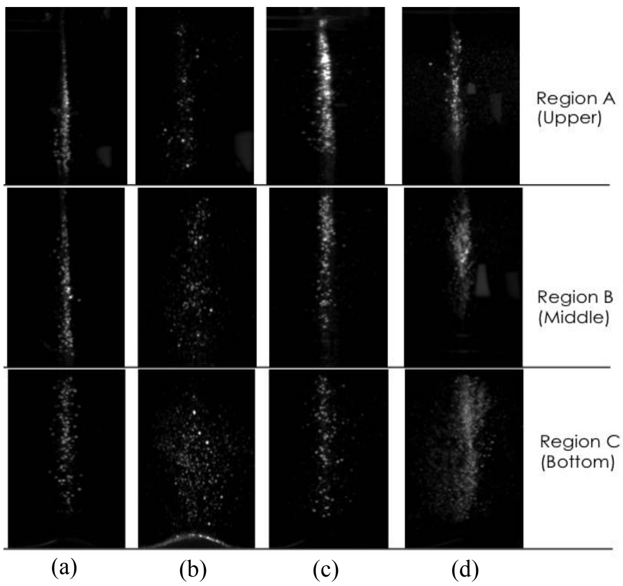

Figure 4: PIV image of particles. (a) Castor sugar (b) Oat (c) semolina (d) tea

In Figure 4(d), tea powder has generated higher concentration compared to oat powder. The finding suggest that the irregular shape and smallest average particle size reduced the distance of the airborne-dust during hindered settling. It is apparent from Figure 4 that, regardless of powder characteristics, the airborne particles and the entrained ambient air form a boundary layer around the core of the particle stream. The boundary layer increased with increasing drop height.

4. Conclusions

The purpose of the current study was to examine the relationship between powder properties on flow pattern during filling operation using a PIV system. This study has found that generally, the flow patterns are strongly depend on the bulk density of the powder and the boundary layer grows with increasing drop height. The current findings add substantially to the understanding of the role of powder characteristics in enhancing safety measures in powder industries.

Acknowledgments

The authors fully acknowledged Ministry of Education for the approved fund (FRGS/1/2015), Center of Excellence for Advanced Research in Fluid Flow (CARIFF), University Malaysia Pahang for the PIV analysis and TATI University College for the support which makes this important research viable and effective.

[1] Majumder A 2007, *Minerals and Metallurgical Proc.* **24**, 237-42
[2] Bhatty J I, Davies L, Dollimore D and Zahedi A H 1982, *Surface Tech.* **15**, 323-44
[3] Zimmels Y 1983, *AIChE J.*, **29**, 669-76
[4] Dollimore D and McBride G 1969, *Analyst*, **94**, 760-67
[5] Gu Z H, 1991 *Gravity flowrates of Bulk Solids From Mass Flow Bins* (PhD Thesis: University of Wollongong.
[6] Zhu H P, Zhou Z Y, Yang R Y and Yu A B 2008, *Chem. Eng. Sci.*, **63**, 5728-70
[7] Jain R 2014, *The Evaluation of the Hindered Settling Behavior of the Ground Calcium Carbonate Suspension* (Master Thesis: The University of Toledo)
[8] Waduge L L L, Zigan S, Stone L E and Belaidi A 2017, *Process Safety and Env. Pro.*, **105**, 262–73
[9] Rani S I, Aziz B A and Gimbun J 2015, *Process Safety and Env. Pro.*, **96**, 14–21
[10] Daniel S, Nadja S, Eberhard S, Raimondas J and Harald K E 2019, *Powder Tech.*, **355**, 37-56