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Predicting concentrations of fine particles in enclosed vessels using a camera based system and CFD simulations

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ABSTRACT

One of the main challenges in industries handling biomass is the consequence of the particle breakage of pelletised biomass in smaller fractions which can lead to fine particles smaller 500 μm that can form dust clouds in the handling and storing equipment. These dust clouds present potential health and safety hazards as well as dust explosion hazards to plant operators because the airborne dust can occur in high concentrations close to the dust explosion limits of the biomass material, during the filling process of storage silos. Preventing dust explosions and the damage of plant infrastructures requires a profound understanding of the particle/air dynamics in the dust cloud circulating in the storage silo. The limited access to the storage facilities as well as the silo size requires a detailed study of the particle/air dynamics at different scales. Lab scale experiments were conducted as a first step to establishing a new optical method for measuring particle concentrations. A small scale experimental rig was fed centrally with different sized wood pellets and a single camera and a laser was utilised to capture the dust concentration in different areas of the silo. According to the experimental results, a higher mass concentration of dust was observed near the silo wall as well as near the main particle jet. However, the mass concentrations were below the explosive limits at the area in between main particle jet and silo wall. These experimental results were then feeding into a 2D CFD simulation representing the particle dynamics in the laser sheet (2D plane). Qualitative findings show a good agreement of the particle/air dynamics between experiments and simulations.

1. Introduction

Biomass generates an increasing interest as renewable fuel and industries handling biomass show fast levels of growths over the last decade and, yet, several challenges remain in the handling, transporting and storing of biomass such as wood pellets.

Dust explosions are a major concern of industries handling combustible bulk materials containing fractions of fines (particles smaller than 355 μm). Dust explosion risks are present in many industries (e.g. power, chemical and food industries) handling wood and paper products, grain and flour, metal products or pulverised coal to mention just a few (Frank, 2004).

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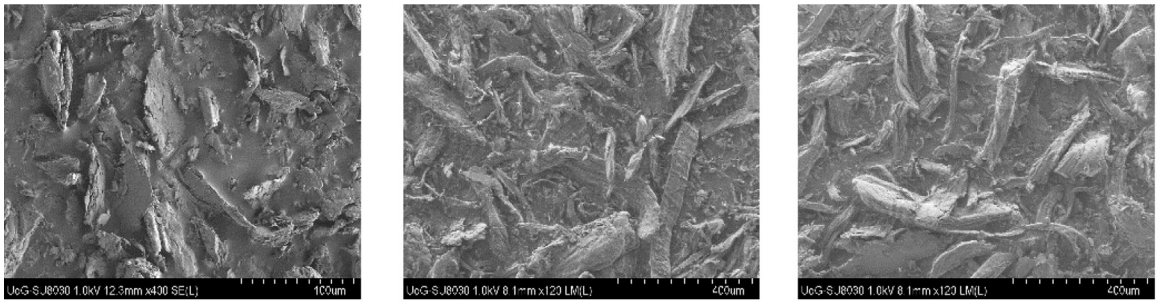

Fig. 1 – SEM (Scanning Electron Microscope) images of wood dust samples with various sizes (a) size range from 60 to 90 μm (b) size range from 100 to 125 μm (c) size range from 300 to 355 μm.

Fig. 2 – The material used in the experiment is a mixture of coarse (a) and fine (b) particles mixed with the mass ratio of 10:1.

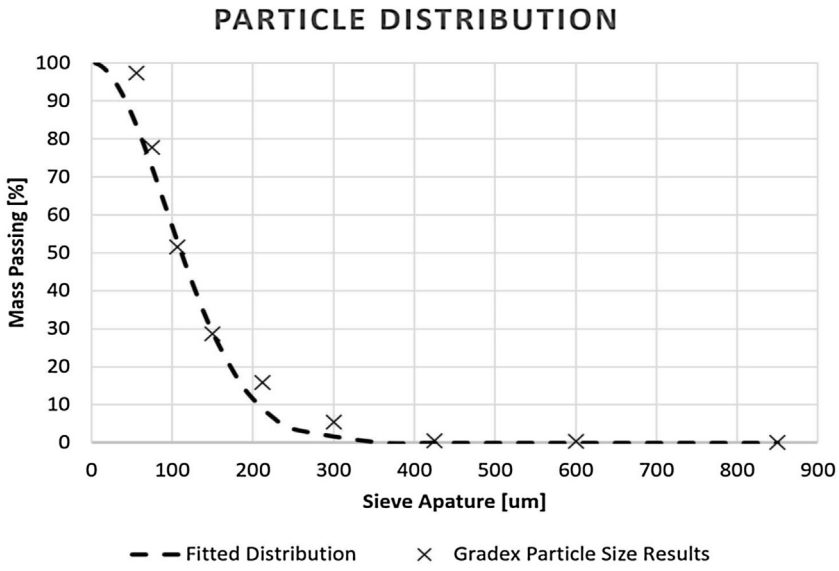

Fig. 3 – Rosin Rammler distribution fitted to sieve particle size results.

The consequences of dust explosion in industrial facilities can be severe for the workforce, and plant operators as such explosions can cause fatalities, injuries and facility damage e.g. to the storage silos (U.S. CSB, 2010).

Dust explosions in storage silos occur in the presence of an ignition source capable of igniting an explosive fuel mixture atmosphere. In the presence of favourable conditions such as dust concentration and air turbulence levels inside the silo, explosions hazards are increased. When dust concentrations in the circulating air inside a closed vessel is within the range of around 300–1500 g/m^3 with a narrow particle size distribution (of between 10 to 40 μm) the highest propensity for dust explosions is present. The quantification of dust concentrations and particle size distributions in the atmosphere–fuel mixture in the storage silo can provide a baseline for evaluating dust explosions risks not only for storage silos but also for industrial facilities in general (Davis et al., 2011, p.839).

The dust concentrations in silos depend on equipment parameters e.g. the operation mode of the silo (e.g. filling or emptying) and material parameters e.g. the natural variations of the particle size distribution of the material handled. Some materials, such as biomass/wood pellets, tend to dust significantly.

The environmental parameters such as temperature and air humidity have to be added to the list of material and equipment parameters when evaluating the amount of airborne fines in storage silos. A large number of parameters influencing the concentration of airborne dust can cause variations of up to 30% between filling and discharge cycles. The large variations of dust concentrations with time in the industrial process require a detailed study of the particle settling behaviour