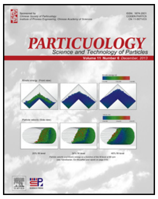
Particuology xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic



A qualitative study on the pulsatile flow phenomenon in a dense fly ash pneumatic conveyor

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ARTICLE INFO

Article history:
Received 31 October 2013
Received in revised form 26 February 2014
Accepted 15 March 2014

Keywords:
Pneumatic conveying
Electrical capacitance tomography
Fly ash
Pulsatile flows
Flow pattern analysis

ABSTRACT

Understanding of the dynamic particulate flow structures within a dense gas-fly ash pneumatic conveyor must be improved in order to better aid its design guidance. The complex pulsatile movement of the gas-fly ash mixture dominates the flow performance within the pipeline, and historically, non-invasive measurement devices such as the electrical capacitance tomography (ECT) were often used to sufficiently capture the flow dynamics. However, inadequate studies have been conducted on the pulsatile flow phenomenon, which directly relate to the gas-fly ash two-phase flow performance. This paper aims to investigate the pulsatile flows using an ECT device. Initially, pulsatile flow patterns under various experimental conditions were obtained through ECT. Pulses within a flow were then characterised into pulse growth and decay segments, which represent the superficial fluidisation and deaeration processes during conveying. Subsequently, structural and statistical analyses were performed on the pulse growth and decay segments. Results suggested that the increasing air mass flow rate led to the decrease of the superficial fluidisation/deaeration magnitude, however, the increase of the superficial fluidisation/deaeration durations. Also, the air mass flow rate was indicated as the dominant factor in determining the pulsing statistical parameters. This research provides fundamental insights for further modelling the dense fly ash pneumatic flows.

1. Introduction

Transport of fine powders (fly ash, cement, pulverised coal, etc.) using a pneumatic conveying system is widely used in the process and power industry. Generally, for fine fly ash, it is capable of being transported in a fluidised dense phase mode within a pneumatic pipeline (Dixon, 1979; Geldart, 1973; Jones & Williams, 2008; Mainwaring & Reed, 1987). In horizontal flows, there is a dense material layer supported by the pipeline bottom in which a retarding force is induced by the friction between the material and the pipe wall. At the upper part of the pipeline, the air phase dominates the flow and a relatively dilute layer is observed. Exchange of the airflow at the interface between the dense and dilute layers presents a profound scenario which exceeds current understanding of such a two-phase flow (Williams, Jones, & Cenna, 2008).

Earlier studies of this complex pneumatic flow were based on a two-phase method which modelled the flow in the air and solids phases separately (Mills, Mason, & Stacey, 1982; Pan & Wypych, 1992). Nevertheless, results predicted using such a method matched poorly with full scale experimental results. Therefore, more insights into the air-fly ash interactions during the conveying process are required.

To better understand the flow dynamics, non-invasive measurement techniques have been developed (Yan, 1996). Among those techniques, the electrical capacitance tomography (ECT) technique has been an ideal tool to obtain instantaneous spatial information for dynamic flows within pneumatic pipelines due to the non-conductivity of the dry air and solids particles (Huang, 1995; McKee, Dyakowski, Williams, Bell, & Allen, 1995; Ostrowski, Luke, Bennett, & Williams, 2000; Romanowski, Grudzien, Aykroyd, & Williams, 2006). With the aid of an ECT device, flow patterns of the material conveyed inside a pipeline can be captured. Results indicated good agreement when comparing to images obtained from high speed video cameras (Jaworski & Dyakowski, 2001; Zhu, Rao, Wang, & Sundaresan, 2003).

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http://dx.doi.org/10.1016/j.partic.2014.03.005

Please cite this article in press as: Chen, W., et al. A qualitative study on the pulsatile flow phenomenon in a dense fly ash pneumatic conveyor. *Particuology* (2014), http://dx.doi.org/10.1016/j.partic.2014.03.005

Nomenclature

d_{50}	mean particle size, µm
ρ_p	particle density, kg/m^3
M_a	air mass flow rate, kg/s
M_s	solids mass flow rate, kg/s
M^*	solids loading ratio
v_{ave}	average air velocity during conveying, m/s
ρ_{bCal}	ECT calibrated bulk density, kg/m^3
ε	ECT permittivity
μ_N	mean for the normal distribution function
σ_N	variance for the normal distribution function
μ_{LN}	mean for the log-normal distribution function
σ_{LN}	variance for the log-normal distribution function
k_G	shape parameter for the gamma distribution function
θ_G	scale parameter for the gamma distribution function
k_W	shape parameter for the Weibull distribution function
λ_W	scale parameter for the Weibull distribution function
x_i	distribution function data
θ	independent sample data
$D_{K\text{–}S}$	K–S test statistics

Using the ECT, pulsatile fly ash flows have been identified. For instance, using an ECT device with a sampling rate at 140 frames per seconds, pneumatic conveying of fly ash ($d_p = 34$ µm) was conducted (Xu, Liu, Wang, & Jiang, 2002). The reconstructed flows showed irregular and pulsatile patterns. Williams, Olszewski, Jones, and Singh (2008) also investigated fluidised dense fly ash pneumatic flows using a 30 frames per second twin-sensor ECT system where the ECT result showed that flows were naturally un-steady and pulsatile.

The objective of this research is to further analyse the pulsatile patterns of fly ash flows obtained from the ECT device in a horizontal pneumatic pipeline. In particular, flow patterns were initially obtained by converting the ECT results into a bulk density based format. These flows were then characterised into superficial fluidisation and deaeration segments using a pulse characterisation technique. Structural and statistical analyses were then carried out on the properties of these segments.

2. Experimental method

The experimental facility used to carry out the tests is shown schematically in Fig. 1. Air from a compressor was fed into a 6-bit choked flow array to control the air mass flow rate. Solids mass flow rate was controlled by the speed of a rotary feeder which moved the material from the loading bin into a 20 m long conveying pipeline (internal diameter of 53 mm). Material entering into the pipe was picked up by the compressed air and conveyed, after passing an elbow bend and a vertical blind-T bend, then back to the receiver bin. The actual solids mass gain and loss information was obtained via load cells at the base of the feed hopper and receiver hopper, from which the mass flow rate was calculated.

The ECT system was embedded in a horizontal section approximately 4 m downstream from the elbow bend with a distance of 0.55 m between the two sensors. Installation at such a position also reduced the non-continuous effect generated by the rotary feeder.

Eight conveying tests were conducted with the fly ash ($d_{50} = 19$ µm, $\rho_p = 2500$ kg/m^3) using different air and solids mass flow rates combinations to achieve a wide range of operating conditions, which are shown in Table 1.

3. Electrical capacitance tomography calibration

The twin sensor ECT configuration enables the measurement of the flow velocity in the pipeline. Each ECT sensor was operated at a

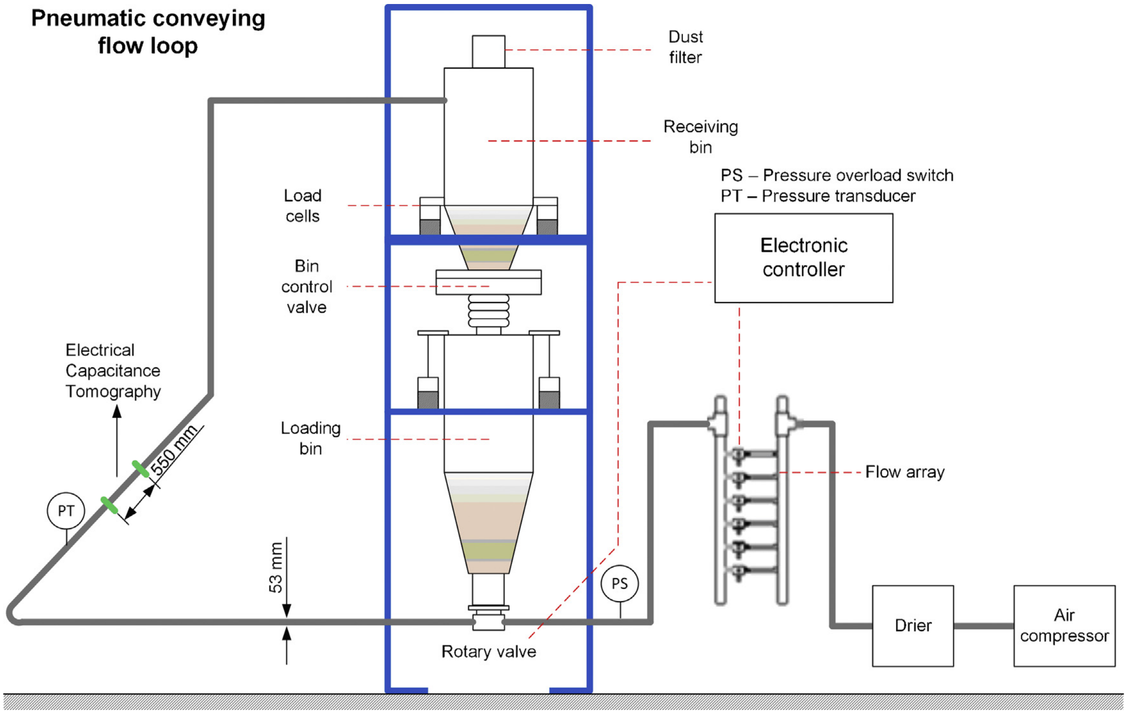

Fig. 1. Schematic of the pneumatic conveying experimental facility.

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