Advanced Powder Technology 23 (2012) 548–557

Contents lists available at ScienceDirect

Advanced Powder Technology

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

Original Research Paper

Flow patterns and velocity fields in two-dimensional thin slice panel with flow-corrective insert

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ARTICLE INFO

Article history:
Received 19 January 2011
Received in revised form 14 March 2011
Accepted 16 March 2011
Available online 30 March 2011

Keywords:
Two-dimensional moving bed
Mass flow
Flow-corrective element
Hopper

ABSTRACT

An experimental two-dimensional (2-D) thin slice panel for studying flow patterns of fine silica sand was designed and manufactured. As supplier of sand was not known at that time, flow properties of the silica sand were assessed without shear tests. A preliminary design of plane-flow hopper of the experimental 2-D panel was assumed to be close to the mass flow conditions. Sand was circulated in the experimental panel to study the steady state flow. Tests of flow patterns suggested typical funnel-flow patterns with stagnant zones in the hopper and in the vertical part of the panel. Stagnant zones near the bottom of the hopper indicated insufficient width of the hopper outlet. Shear tests for estimation of flow properties of silica sand were carried out additionally and two methods of how to transform the funnel flow of sand to the mass flow were followed up; (a) existing 2-D panel was retrofitted with flow-corrective element, and (b) the width of outlet in existing experimental panel was widen into the size, calculated according to mass flow conditions. Both modifications were proven to be successful and the last-in first-out funnel flow was transformed into first-in first-out mass flow of sand. Velocities of individual tracer particles were measured during mass flow and velocity field was evaluated. Velocity profile of particles in the vicinity of flow-corrective insert was studied in detail.

1. Introduction

Many granular moving bed apparatuses, as for example silos, bunkers, moving bed dryers, granular bed filters and adsorbers are still built without considering the flow behavior of the bulk solid to be stored or processed. On the principles known from soil mechanics, Jenike [1] described the behavior of bulk solids by introducing the yield locus of bulk solids. Furthermore, he derived a theory [2,3] describing the stresses in silos, especially in the hopper section. Jenike's theory of gravity flow of bulk solids in silo helps to design the conical or wedge shaped hoppers with circular, square, or rectangular ($L > 3b$) outlets, where "b" and "L" are characteristic dimensions of outlet. Jenike defined the terms "mass flow" and "funnel flow," which characterize the flow regime and flow patterns in a silo.

When "mass flow" is established, there occurs a uniform descent of all the bulk solids inside the silo with no formation of preferential paths. Otherwise stated, the velocity vectors of the various particles in the silo at a cross-section plane of the silo are, if not identical, very similar to one another. When "funnel flow" is established, there is, instead, non-uniformity in the values of velocity vectors of the various particles along a silo cross-section. More particularly, velocities of particles at the central portion of the silo at the same cross-section have a clearly greater value than the velocities of particles close to the silo sidewalls. This phenomenon is indicative of the fact that at least one descending preferential path has been established in the material at least at the central portion of the silo.

The mass or funnel flow patterns occurring as bulk solid discharges under gravity from a silo have been investigated by many researchers [4–6] using a number of different experimental techniques. A review of these experimental works has been conducted by Schwedes [7].

One common approach to study flow patterns has been employed. The two-dimensional (2-D) model of moving bed apparatus with transparent walls was carefully filled with layers of differently colored particles, so that changes in the colored stratification could be observed during the flow. Such experiments in models of cylindrical silos, conical hoppers or rectangular bunkers helped to give an insight to the nature of gravity flow of free-flowing and cohesive materials, and allowed the influence of the wall

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doi:10.1016/j.apt.2011.03.008