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Original Research Paper

Effects of process parameters and hopper angle on segregation of cohesive ternary powder mixtures in a small scale cylindrical silo

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ABSTRACT

Segregation of two ternary powder mixtures at filling and at discharge of a 0.4 m^3 cylindrical silo has been investigated experimentally. The material distribution at silo filling was determined by sampling from the upper layers of the heap at different radial positions and with varying levels of fill. Discharge flow patterns were elaborated with tracer objects in the majority of experiments and the composition of the bulk solids during emptying was determined by sampling across the entire discharge stream. The effects of free fall distance and intermittent discharge and filling on segregation at filling as well as the effect of hopper angle on segregation at discharge were investigated. Furthermore, the influence of filling rate is discussed. Based on the results, side-to-side segregation with accumulation of fine particles to the silo walls clearly increases with increasing free fall distance. Segregation is also aggravated in situations where the silo is filled and discharged intermittently, because the shape of the powder bed's surface changes when a portion of the silo contents is withdrawn. The effect of filling rate remains unclear and should be more deeply investigated in the future. The hopper angle determines the discharge flow pattern, i.e., funnel or mass flow, but the composition of the powder mixture towards the end of complete emptying is mainly determined by the material distribution at the levels of fill that are withdrawn last. The presented findings increase the understanding of the effect of process parameters and silo design on segregation, and can be used for mitigating the detrimental effects of segregation of bulk solids handled in silos.

1. Introduction

Segregation is the opposite of mixing. For an initially well mixed particulate solid mixture, segregation induces partial – or sometimes nearly total – separation of the constituents. Segregation leads to lowered blend quality and causes flow problems in bulk solids handling equipment. Although segregation has been reviewed in many studies [1–5], it is a phenomenon that is still not fully understood. Segregation can occur for materials consisting of particles with different properties such as size, density, shape, surface texture, electrostatic charge, micromechanical properties, and molecular surface effects [6]. Segregation mechanisms are often used to explain why particulate solids segregate under specific circumstances and what the outcome in terms of the spatial or temporal distribution of the constituents of a mixture will be. Several segregation mechanisms have been identified including rolling, sieving or sifting, percolation, angle of repose, trajectory, air current, fluidization, embedding, and impact segregation as summarized in [7]. The occurrence and relevance of each of these depend on the properties of the bulk solid itself and on the conditions it is exposed to. Several segregation mechanisms have been examined in detail and most often these investigations were performed with segregation testers constructed for the purpose [8–16].

Filling of bulk solids into confined vessels such as silos basically involves the process of heap formation. In systems where the bulk solid consists of different-sized particles, fine particles may accumulate at the heap apex as a result of sieving or sifting, percolation and rolling segregation. The same segregation mechanisms may also be active at silo discharge, for example, in funnel flow in the case of size differences for free flowing bulk solids. The basic underlying phenomena of these mechanisms have been extensively investigated by others [7,8,10,11] and the overall segregation patterns caused by the mechanisms in silos, bunkers or other confined cavities have also been examined earlier [17–20].

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