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In-situ monitoring of axial particle mixing in a rotating drum using bulk density measurements

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Abstract

A device is described for measuring changes in the local composition of particulate materials in a rotary mixer by continuously monitoring changes in the bulk density. The bulk density is measured using a small cup mounted to the mixer wall that fills with powder during rotation through the bed of particles in the lower part of the mixer. The mass of material in the cup is measured using a load cell during rotation of the cup above the free surface of the particles, and the cup empties before re-entering the particle bed. For mixing of materials with a difference in either particle density, or packing density, the localised bulk density measurement gives a good measure of mixing progress. The measurement device is demonstrated in a 1 m diameter horizontal rotating drum in which two materials are mixed along the axis of the drum. Measurements of the rate of dispersion along the axis are consistent with other work in inclined rotary kilns and can be fitted with a simple diffusion model for the axial mixing of the two species.

Keywords: Axial mixing; Dispersion; Bulk density; In-situ measurement; Particle mixing

1. Introduction

1.1. Real-time monitoring of particle mixing

In many batch mixing operations the components to be mixed are added separately to the mixer in discrete dumps and at the start of a mixing cycle there are significant non-uniformities in composition throughout the mixer volume. The principal objective of the mixing process is to make a uniform blend of the constituent components, and usually, to ensure that the composition of samples taken at the end of the mixing cycle is within specified limits. Mixing also occurs in a number of rotary systems such as kiln driers or drum granulators. The feed to these may be added either batch-wise or continuously and it is important that different components, and indeed different size and density fractions within a single component, are distributed uniformly along the rotating axis to ensure a uniform product and stable operation of the process.

One of the challenges in industrial practice is to monitor the progress of mixing within the process, particularly for batch operations. A reliable method for determining the degree of mixing enables the operation time of the mixer to be optimised to avoid unnecessary processing costs, and the mixer to be controlled to give optimum rates of mixing and to minimise segregational effects. The most common approach currently used is to take periodic samples of powder either from within the mixer or as the powder emerges from the process. This has been used, for example by Sai et al. [1], to study residence time distributions in rotary kilns. This is a very direct way of measuring the state of the system, but it still requires a careful approach to obtain meaningful results. A commonly used sampling tool, the sampling 'thief', involves inserting a sampling cup into the particle bed to capture a small section of the particle bed. Even this simple process using state-of-the-art equipment can result in distortion of the particle bed so that the particles collected are not representative of the bulk from which they have been collected, as has been demonstrated by Muzzio et al. [2]. The process of

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taking a sample of material also changes (to some degree) the state of the system, and may influence any subsequent downstream measurements in the system. Samples from a process are also generally analysed off-line, so that the measurement is not in real time, and sampling in general is impractical in closed or batch systems that require stopping and opening of the process.

An alternative to sampling that avoids the disturbance associated with the sampling tool is described, for example, by Brone et al. [3] for analysis of mixing in a V-Blender. The technique involves solidifying the particle bed with a binder and then slicing the bed into sections. This is an effective technique for analysis of mixing systems, but has limited industrial application for process monitoring.

Real-time monitoring of mixing has been achieved with a number of *in-situ* measurement techniques. These generally fall into two categories; ones that involve detecting the passage of a tracer introduced into the mixer, and ones that measure natural variations in the material being processed. The introduced tracer methods include the use of positron emission particle tracking (PEPT) [4–6], and other radioactive tracer techniques [7–10]. The PEPT technique, developed at the University of Birmingham, has been widely applied to a range of particle flow systems by the group, including horizontal rotating drums as described by Laurent et al. [4] and Parker et al. [5], and ploughshare mixers [6]. The technique involves introduction of a single radioactive particle to the particle bed, and tracking of this particle in three dimensions by measuring back-to-back γ-rays released by the particle. By tracking the particle for a long period of time in a closed system it is possible to make detailed statistical representations of the overall particle motion. Austin et al. [7] describe another approach to measuring particle dispersion in a continuous flow horizontal wet milling drum. The passage of the tracer past fixed measurement points was measured from outside the mill, and residence time distributions were calculated. Similar radioactive tracer techniques have also been applied to a range of other particulate systems to measure particle velocities and rates of dispersion, such as by Harwood [8] who studied segregation in a vibrating bed of powder, Barry et al. [9] who investigated radial velocity variations in standpipe flow, and Tallon et al. [10] who measured particle dispersion in a pneumatic conveying line. The use of radioactive materials, however, is undesirable in many industries, and the use of introduced tracer particles in general is impractical for industrial use.

Other measurement techniques include the use of magnetic resonance imaging [11], near infrared spectroscopy [12,13], UV fluorescence [14], and visual or optical observations [15–18]. These techniques measure particle mixing by use of either an introduced tracer material, or by measuring natural differences in the physical properties of the different species. In the latter case the natural differences in particle properties often only exist by careful selection of the components being mixed, and in this respect may be limited to experimental systems rather than general industrial application. The magnetic resonance imaging system described by Nakagawa et al. [11] was used to study segregation of a pharmaceutical compound in a horizontal rotating drum. The MRI scanner was able to distinguish different particle sizes based on the different ratios of surface coating to liquid content of the different sized particles. This distinction is likely to be limited to a small range of systems and would be expensive and cumbersome to operate in an industrial environment. Measurements using near-infrared spectroscopy are described by Berntsson et al. [12] and Sekulic et al. [13]. Particles with different composition give unique reflectance (and transmittance) responses, so that an average concentration of two or more components can in principle be calculated in the detecting region around the tip of the probe. This could potentially be applied to a number of industrial systems, but cannot be applied to mixing and segregation of different size fractions of the same material powder, and may be limited in systems where, for example, moisture content is variable within a particular component or where humidity or surface moisture is present. Near-infrared measurements can also be made non-intrusively if measurements are limited to near the walls of the mixing vessel. UV fluorescence [14] is a property limited to a small number of materials and has limited industrial application with other materials. Optical techniques [15–18] are the most common approach, and experimental studies of mixing have been carried out with great success using dyed, or naturally different coloured, materials. Qualitatively it gives rapid results that are easy to interpret and understand, but quantification for use in industrial control becomes more difficult. Quantitative measurements can be carried out, such as by using image processing software, to determine proportions of different colours [17] or by actually counting tracer particles [15] but these may not be industrially applicable due to the need for transparent apparatus and introduction of tracer material. Optical observations are also often limited to observations of the surface of a powder bed and may not reflect the overall behaviour of the system.

A non-intrusive acoustic system, described by Evans [19], measures changes in the acoustic properties of the mixture as the mixing progresses, but this measurement is qualitative and the mechanism relating the signal to the quantitative state of the mixture is not immediately apparent.

An alternative approach is to monitor changes in the local bulk density of the mixture. In many natural industrial mixing operations there are differences in the density of the components, and also their size and size distribution. The local bulk density of a mixture of two or more components will depend on the proportion of each component present, on the particle density of the respective components, and on how the two materials pack together. Thus it would be possible in many systems to get a measure of the state of a mixture by measuring its bulk density. With suitable calibration, it is also often possible to get a quantitative measurement of the mixture composition. Bulk density is a commonly measured particle property and in some industries it is common practice to check mixture quality by measuring bulk density at the end of a cycle.

Davies and Murray [20] have previously described a method for continuous in-line measurement of powder bulk density. The measurement is made by passing the powder flow through a measuring cup of known volume and recording the mass of material in the cup with a load cell. The instrument can be applied to an industrial process, for example, by diverting part