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Determination of the mixing time in a discontinuous powder mixer by using image analysis

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ABSTRACT

This study reports on research results in the field of powder mixing in a discontinuously operated charge mixer. The mixing time for a confidence interval can be determined from the mixing efficiency that characterizes the mixing of the participating solid components as a function of the mixing time. The mixing efficiency is determined here with the help of an image analysis method developed for these purposes. The particle fraction, that is interesting in terms of its distribution, is partially replaced for this purpose by a similarly behaving but optically well-identifiable tracer material. A dispersion coefficient can be obtained from the analysis of the mixing trial. The practical application of statistics on image analysis is described and discussed along with a description of the possibilities and limitations of the measurement method. The description of the procedure to determine the dispersion coefficient is built on that.

1. Introduction

Mixing of dry or moisturized powders is a unit operation in process engineering processes, and will be found in the construction-, food-, pharmaceutical-industries, as well as in other fields. The user's objective when employing a charge mixer is to attain a defined homogeneity in the solids to be mixed within a shortest possible mixing time. The change in the mixing quality over the mixing time is described by the mixing efficiency. The mixing efficiency is determined in the classical manner, representative solid samples are taken out of the mixing chamber and are analyzed outside for their composition. This procedure of powder sampling is based on a statistic background. Each individual measurement point in the mixing quality curve represents the result of several samples that were taken and whose number is determined by the user. These samples must then be analyzed outside the mixer with a relatively major effort. The more samples are taken out of the mixing chamber, the closer to the expected value will be the result of the concentration measurements. But, as the sample is taken, an always irreversible interference is generated at the sampling site, whose action critically influences the surrounding mixture. Systematic sampling at firmly defined sites is necessary in order to be able to make meaningful comparisons among mixing efficiencies against the background of differing initial states. The described procedure has already been illustrated in detail in the available literature (Raasch and Elsässer, 1995; Hauser et al., 1989), and it was also discussed and investigated. Just as sampling is done according to the state of the art, the mixing chamber must according to Koch et al. (1996) be subdivided systematically into individual segments. By means of a suitable sampler and support by the random generator, the individual samples to be analyzed are selected and removed from the various segments. The samples are then analyzed outside the mixing chamber. If the samples to be analyzed contain components that can harden, then measurement methods used outside the mixing chamber are rather unsuitable. The problem might be solved by optical or also radiometric measurement methods that facilitate the analysis directly in the mixing chamber itself.

We know of experiments that are intended to reduce the effort involved in the reevaluation of continuous/discontinuous powder mixers with the help of modern spectroscopy methods according to Habermann (2005), Holzmüller (1984), Merz (1973), Weinekötter (1993), and Kehlenbeck (2006). There exist a lot of more measurement methods like in Lai and Cooney (2004), Lai et al. (2004), Ehrhardt et al. (2005), and Hardy et al. (2007) to estimate powder samples. But these methods are of limited use on account of the limitations of the permissible sample volume. Their calibration constitutes a problem for all measurement methods because any change in the solid system requires a renewed calibration. Errors in the determination of the concentration result if this is not complied with. Most recently, measurement methods have been used in charge mixers where the discontinuous mixer was either completely transilluminated with X-rays or where positron emission

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particle tracking (PEPT) measurements were employed according to Yang and Fu (2004), Ingram et al. (2005) and Puyvelde (2006). These methods likewise are suitable only for laboratory mixers with limited capacity. Optical measurement methods with fiber optic waveguides and CCD-cameras were used in Ålander et al. (2003), Aoun-Habbache et al. (2002), Berthiaux et al. (2006), Eichler (1998), Khakhar et al. (1997), Landwehr (2005), Metcalfe et al. (1995), Muzzio et al. (1997), Puyvelde et al. (1999), Realpe and Velázquez (2003), Stalder (1993), Wightman et al. (1996), and Muzzio et al. (2008). Here, image analysis was in all cases used for the purpose of characterizing the mixing state. These analysis methods are particularly suitable when one must characterize particles of different color. The above-mentioned authors, that use image analysis for powder mixing, could not always get along without taking samples from the mixing chamber—somethingthat necessarily had to be accompanied each time by brief interruptions of the mixing operation.

The progress in mixing analysis, presented in this study, resides in the development of an image analysis method without sample taking for direct determination of the concentration curve and that the mixing efficiency during the mixing process in the mixing apparatus. A CCD-video camera records the mixing process throughout the entire mixing time so that one can at any time fall back on certain specific sequences and one can generate any number of measurement points for the mixing efficiency. One advantage inherent in this measurement method is represented by the fact that the camera can be adapted in a flexible manner if there is a change in the structural size of the mixer or of the sample volume. Besides, at all times there is access to the raw data so that one might possibly be able to vary the analysis method. Finally, moved images can, over the time of the entire mixing process, illustratively clarify the procedure going on in the powder mixer.

2. Experimental apparatuses, structure of experiments, and product characterization

2.1. Experimental apparatuses and structure of experiments

The experiments were carried out on the horizontal twin-shaft-paddle mixer supplied by Firma ELBA-Werk Maschinen GmbH. According to Fig. 1, the volume of the twin-shaft-paddle mixer is $V = 120\,\mathrm{L}$. The powder mixer is equipped with a spiral mixing tool. The characteristic feature of the twin-shaft-paddle mixer is represented by the fact that the two mixing tools intersect each other in the central part of the mixing chamber. These tools move opposite to each other and convey the product from the outer edge of the trough toward the interior. In the case of the twin-shaft-paddle mixer, the mixing tool running along the wall has a diameter of $D_W = 550\,\mathrm{mm}$. The ratio of the drum diameter to the length is $D_T/L \approx 2$. The filling ratio ϕ corresponds to approximately $\phi \approx 50\%$. The revolutions per minute n can be adjusted phaselessly up to 49 rpm. All mixing trials are run at a constant revolutions per minute of $n = 15\,\mathrm{rpm}$. The powder mixer is employed in practice to process concretes and mortar with differing mixing times. In the average mixing runs, the mixing times are approximately $t_M \approx 30\,\mathrm{s}$ according to Charonnat and Beitzel (1997).

The Sony VX2100E video camera used here has a resolution of 720 pixels × 576 pixels with an image rate of 30 images per second. By positioning the video camera perpendicularly above the mixing chamber, one can continuously observe or record the mixing procedure. A 1000-watt halogen lamp so illuminates the mixing chamber that shadow formation by the mixing tool and the trough rim can be greatly reduced according to Fig. 2 and the influence of foreign light can be kept small so that these potential error sources can be disregarded during the analysis.

Fig. 1. View of the mixing chamber of the twin-shaft-paddle laboratory mixer with spiral mixing tool.

Fig. 2. Side view of the perpendicularly positioned video camera.

2.2. Product characterization for tracking the powder flow

Special color particles (tracer particles) are used for the mixing experiments; these particles could be identified adequately well by