Mixing of Nanosized Particles by Magnetically Assisted Impaction Mixing in Dry and Fluid Suspension

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Abstract

The mixing of nano-scale particles using a novel dry mechanical mixing technique called magnetically assisted impaction mixing (MAIM) has been studied experimentally in this work. Intensity of Segregation was evaluated at the micron length scale based on field emission scanning electron microscopy (FESEM) images coupled with the energy dispersive x-ray spectroscopy (EDS). In order to achieve the homogeneous mixture of nano-particles, MAIM process was optimized by studying the effects of magnet-to-sample ratio (1:2, 1:1, 2:1, 5:1, 10:1), processing time (5 to 120 mins), magnet size (size ranges of 2360 to 1700 µm, 1400 to 850 µm, and 1000 to 600 µm), and constituents of the mixture (binary systems of SiO_2+TiO_2 and SiO_2+Al_2O_3).

Introduction

Powder mixing is an important and extensively researched area in many industrial sectors such as chemicals, pharmaceuticals, food, cosmetic, ceramic, and electronics during the past several decades [1-2]. However, there are serious challenges faced in handling and homogeneous mixing due to high cohesion and tendency to form large, difficult to break agglomerates that form due to strong inter-particle forces. In fact, conventional methods for powder mixing cannot mix at scales smaller than about a few microns or even hundreds of microns because they fail to break the primary aggregates [3-8].

The focus of this paper is on the Magnetically Assisted Impaction Mixing, which is an environmentally benign mixing technique. In MAIM, a magnetic field is created from the surrounding electromagnetic coil and the magnetic particles undergo agitation. The magnetic particles undergo rotational and translational motion, inside the container, creating a fluidized state for the nanoparticles. Magnetic particles collide with the agglomerates of nanoparticles, and other magnetic particles or the walls of the container, transferring the energy from the generated momentum. It is believed that the collisions between magnetic particles and the agglomerates under appropriate operating conditions should contain enough energy to deagglomerate the nanoparticle agglomerates and promote mixing.

A LEO 1530 VP Field Emission Scanning Electron Microscope equipped with an Oxford UTW X-ray detector was used to obtain quantitative analysis of the Intensity of

Segregation. Two representative areas of 55 x 40 □m at 5000 times magnification were randomly chosen on both the tablet surfaces. The EDS was used to obtain normalized compound composition from 100 points, arranged in a 10 x 10 grid, for each of the areas. Four hundred total points obtained for each mixture were used to calculate average concentrations (μ_a and μ_b) and variance (σ^2). As a basis to compare the homogeneity of a mixture, the Intensity of Segregation, a dimensionless number, is employed in this work. Intensity of Segregation, which was originally developed by Danckwerts [9], is calculated by dividing the variance by the two mean values of each component compound percent. The Intensity of Segregation for a perfect random mixture would be 0, while for completely unmixed mixtures the Intensity of Segregation it would be 1.

Results

Mixing can be controlled primarily through the processing time and the amount of magnets. Figure 1 is a graph of intensity of segregation versus time for multiple magnet-to-sample weight ratios. When more magnets are introduced into the system, and a longer processing time, the intensity of segregation decreased, indicating a more dispersed mixture. When graphing the intensity of segregation versus the combination of time and the number of magnets used in each of the conditions, the data points fall together, forming a single line, Figure 2. The same trend occurs when comparing different sizes of magnets, in Figure 3.

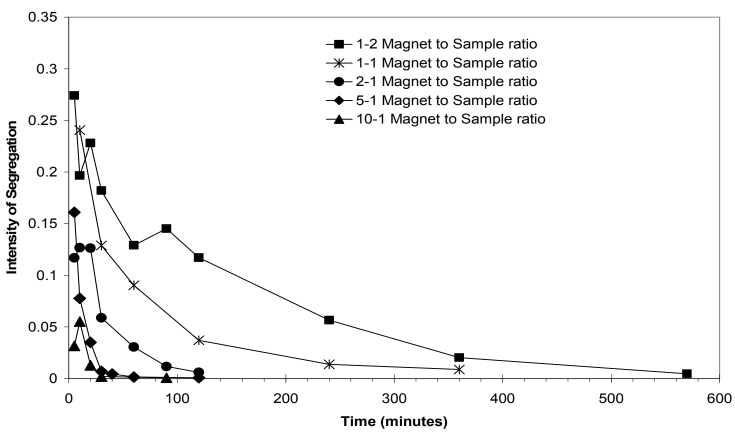


Figure 1. Intensity of Segregation versus time for various mixing times for SiO_2/TiO_2 mixtures and a magnet size range of 1400-850 microns.

Powders that are more cohesive compact on the bottom of the container forming a cake, while the magnets remain on top. In this situation, only limited mixing can take place before there is no longer interaction between the constituents and the magnets. In such cases, we looked into mixing the constituents in a liquid medium, water. Studying the same magnet-to-sample weight ratios, similar trends can be seen with the wet mixing as with the dry mixing. When comparing Intensity of Segregation with time and number of magnets, the different magnet-to-sample weight ratios condensed into a single line. The wet mixing data is presented in Figure 5. By controlling the mixing time and the number of magnets used, a specific intensity of segregation can be obtained referring to approximate agglomerate sizes in the mixture.

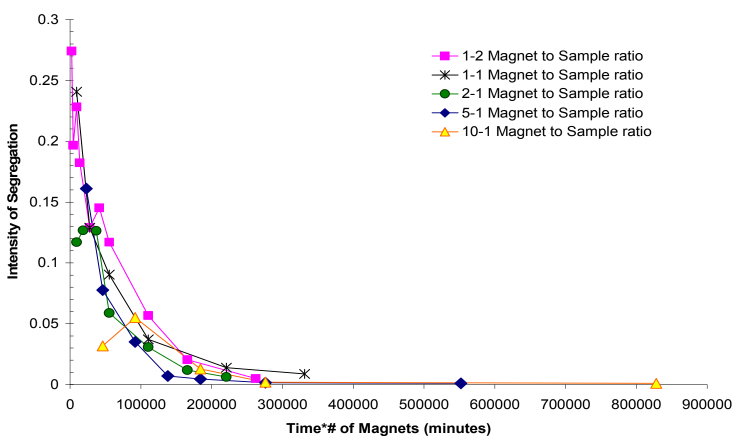


Figure 2. Intensity of Segregation versus time*mass of magnets/mass of powder sample for the magnet to sample ratios of 1:2, 2:1, 5:1, and 10:1 with a magnet size range of 1400-850 microns for SiO_2/TiO_2 mixture.

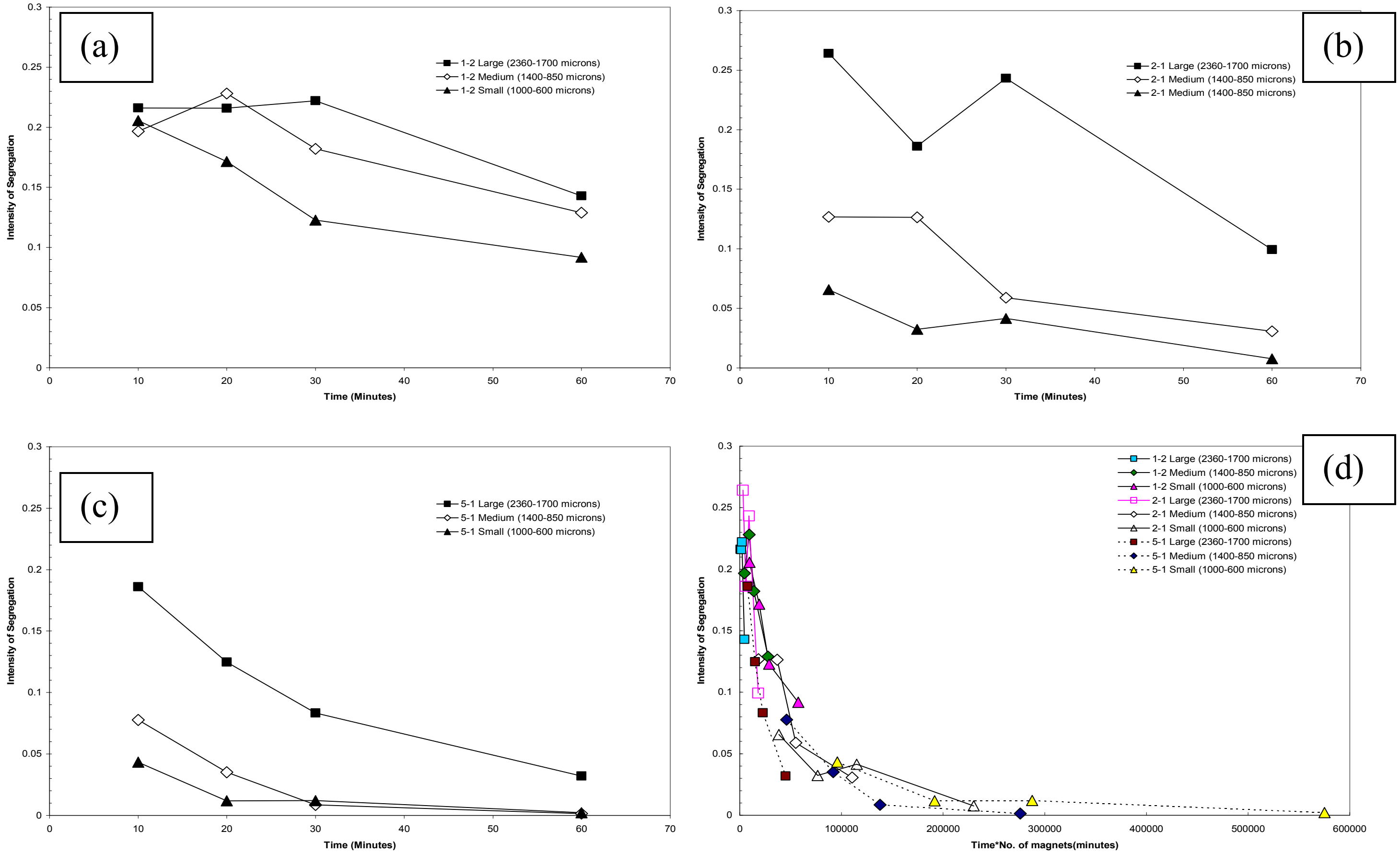
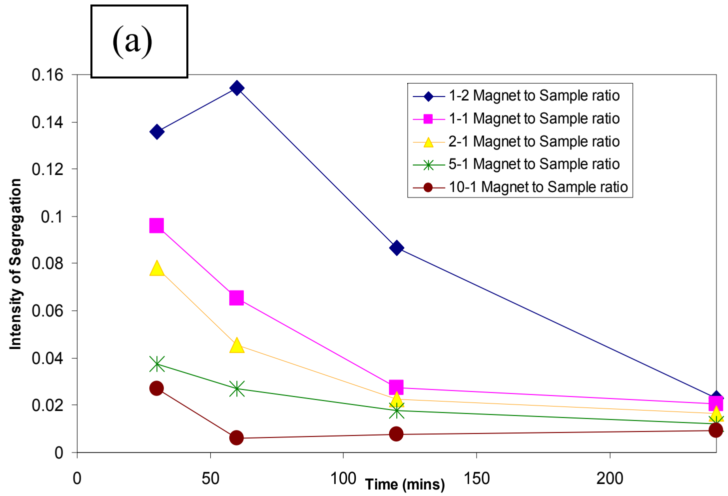


Figure 3. Intensity of Segregation versus time for SiO_2/TiO_2 mixtures with various magnet sizes and a magnet-to-sample ratio of (a) 1 to 2, (b) 2 to 1, (c) 5 to 1. Intensity of Segregation versus time*number of magnets for magnet-to-sample ratios of 1:2, 2:1, and 5:1 (d).



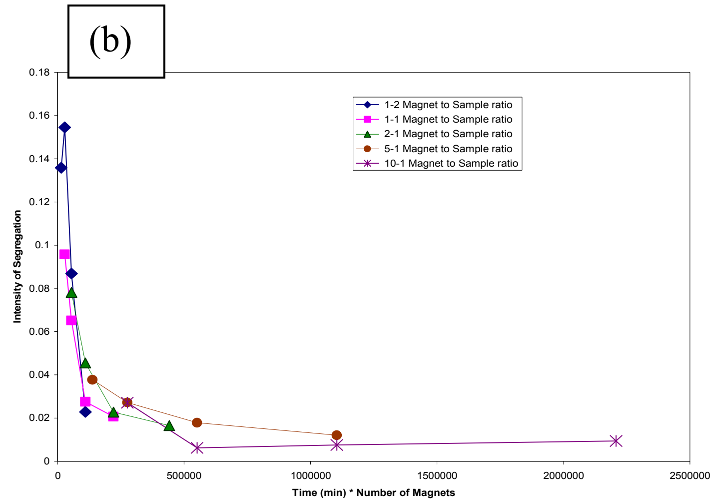


Figure 5. Intensity of Segregation versus time for magnet-to-sample ratios of 1:2, 2:1, and 5:1 with a magnet size range of 1400-850 microns for wet mixtures of SiO_2/TiO_2 (a). Intensity of Segregation versus time*number of magnets for magnet-to-sample ratios of 1:2, 2:1, and 5:1 with a magnet size range of 1400-850 microns for wet mixtures of SiO_2/TiO_2 (b).

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