MIXING AND SEGREGATION IN 3D MULTI-COMPONENT TWO-PHASE FLUIDIZED BEDS USING X-RAY COMPUTED TOMOGRAPHY

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Abstract
To operate a fluidized bed reactor most efficiently, one needs to have a good understanding of the hydrodynamics inside the bed as well as a good understanding of the mixing and segregation patterns that occur if the bed is multi-component. Many studies have been carried out in an attempt to address these issues, and the findings have contributed to make a variety of processes more efficient. However, since fluidized beds are an opaque medium, it remains difficult to experimentally investigate hydrodynamics and mixing/segregation patterns without significant trade-offs. This study discusses experimental efforts aimed at understanding mixing and segregation in multi-component cold-flow 3D fluidized bed reactors.

Introduction
Academic approaches to better understand the operation of these vessels have been found to date back as far as 1955 [1]. Since then, many studies have been carried out with varying objectives, mostly addressing specific applications. However, since fluidized beds are an opaque medium, trade-offs need to be made to allow for measurements of various parameters. In general, measurement techniques can be divided into invasive and non-invasive measurement techniques. Invasive measurement techniques can give insight into a variety of parameters inside the bed when operated, but, due to their nature, have the potential of altering the processes and behavior of the bed. Non-invasive measurement techniques have the advantage of not interfering with the fluidized bed, but have often been found to yield unsatisfying results or required other trade-offs that altered size, shape, or operating parameters of fluidized beds typically found in industry. As an example, several researchers use optical means to record experimental data [2-4] but, in order to make the fluidized bed transparent, they focused on only a very thin 2D fluidized bed. In this case, valuable information can be gathered with the trade-off of highly increased wall effects and lower particle-particle interactions. Segregation studies have also been conducted using computational fluid dynamics models (CFD) for fluidized beds [5; 6]. However, since experimental data are very limited, the accuracy of these models is too.

To further improve the usage of fluidized beds in industrial applications and assist the computational development of these facilities, detailed experimental data from 3D fluidized beds gathered through measurements that do not alter their behavior are necessary. For this study, a non-invasive measurement technique called X-ray computed tomography (CT) has been used to experimentally investigate mixing and segregation in 3D fluidized beds. The Particle Segregation Number (PSN) and the Cube Analysis (CA) quantify bed "mixedness" and the level of segregation. The method and analysis techniques are explained in detail and the findings are reported. The fluidization gas flow rate, particle size, mixture ratio, and humidity of the gas stream can have a significant effect on the level of segregation in a fluidized bed. The newly developed analysis tools have been proven to represent the varying levels of segregation sufficiently and have been found to be superior to previous introduced measures.

Selected Results
Figure 1 shows an example of an analysis using the PSN to illustrate the effect of superficial gas velocity on the mixedness of particles in the bed. The particles used are glass beads in the size range of 500-600 µm as the inert bed material, mixed with ground walnut shell in the size range of 500-600 µm and 800-1000 µm as the second component. The superficial gas velocity is applied in multiples of the minimum superficial gas velocity (U_{mf}) for a full bed of glass beads.

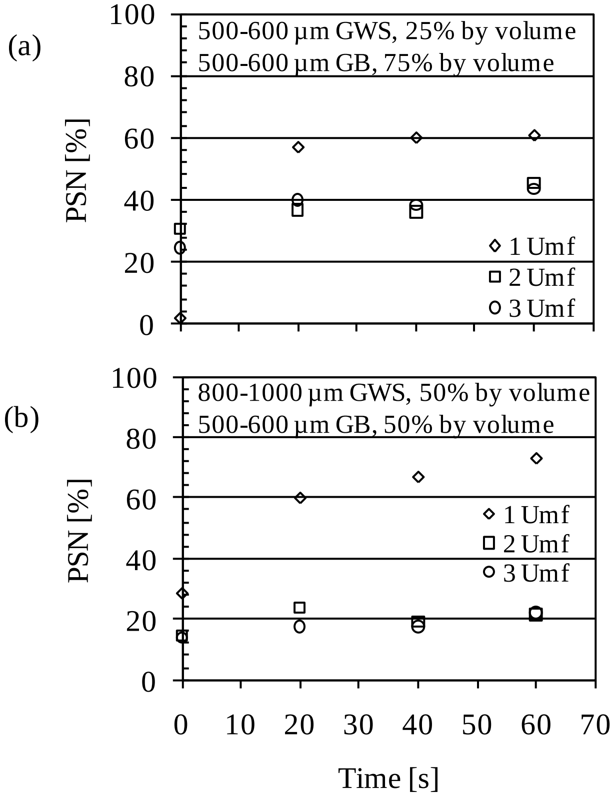

Fig. 1: PSN results for: (a) 25% 500-600 µm GWS with 75% 500-600 µm GB, and (b) 50% 800-1000 µm GWS with 50% 500-600 µm GB, both fluidized for 20 second intervals at U_g = 1, 2, and 3 U_{mf}, illustrating the effect of superficial gas velocity.

The experiments showed that a superficial gas velocity of just above the minimum fluidization velocity causes the bed material to segregate. Lighter particles (GWS, flotsam [7]) will flow to the top, heavier particles (GB, jetsam [7]) sink to the bottom. Higher flow rates promote mixing, i.e., as the flow rate is increased, segregation becomes less.

Conclusions

A new and innovative way to study mixing and segregation of particles in a fluidized bed reactor using X-ray computed tomography has been introduced and the validity and repeatability of the concept has been shown. This allows for non-invasive measurement of particle distribution inside the bed and valuable information about the mixing and segregation behavior can be obtained. The advantage of this approach is that wall-effects are not enhanced, particle-particle interaction is not hindered, and flow conditions are most natural.

In addition, two new analysis tools have been developed, the PSN and CA, which are useful for characterizing the condition of a two-component fluidized bed [8]. The results of all experiments are published in [9].

The results of this study provide a new benchmark in terms of experimental capabilities and are a breakthrough for studying mixing and segregation in fluidized beds.

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