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Continuous segregation of binary heterogeneous solids in a fast-fluidized bed

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ABSTRACT

Continuous segregation of binary heterogeneous solids (different density mixtures) is carried out in a gas–solid fluidized bed to study the effects of gas velocity, solids feed rate, feed composition and density difference of solids on the separation factor (recovery of flotsam at top outlet) and the quality of the product (purity of flotsam at top outlet) in a continuous fast-fluidized bed. The holdup of the bed material is obtained in each experimental run. It is observed that the separation factor decreases with increase in solids feed rate or density difference of solids, and increases with gas velocity or proportion of flotsam in the feed. The quality of the product decreases with increase in gas velocity or solids flow rate, and increases with feed composition or density difference of solids. The experimental results show that the separation factor and the quality of the product are more sensitive to gas velocity than to other operating parameters. Empirical correlations for predicting the separation factor and quality of the product are proposed based on the Richards model for individual flotsam mass fraction in the feed, and the predictions agree satisfactorily with the present experimental data.

Introduction

One way to separate particles is to use a fluidized-bed classifier, in which lighter/smaller particles tend to segregate and float to the surface of the bed, forming what is known as *flotsam*, whilst the heavier/coarser particles tend to sink, forming what is known as *jetsam*. In industrial practice, fluidized beds are generally composed of particles of more than one size. The fluid velocity usually exceeds the terminal velocity of the finer particles (hereinafter referred to as *fines*), which are carried out of the bed in the exit stream. This phenomenon is known as *elutriation*, and is a very convenient technique for classifying a granular mixture into its constituent components according to size and/or density. The amount of entrainment decreases as the gas exit is elevated further, and finally a level is reached above which entrainment becomes approximately constant. This characteristic gas-exit height is known as the *transport disengaging height* (TDH).

The literature contains countless studies on the segregation of particles in batch fluidized beds. However, relatively little attention has been paid to the segregation of particles that are fed in continuously and are discharged from the top and bottom. Krishna and Rao (1963) investigated continuous classification of binary homogeneous mixtures in a fluidized bed. They studied the effects of gas velocity, solids flow rate (SFR), feed composition, ratio of particle diameters and reflux on the performance of the unit, and developed correlations in terms of operating and geometric variables. Gel'perin, Ainshtein, Kvasha, Kogan, and Vil'nits (1964) investigated the separation of a homogeneous mixture (continuous size distribution) in straight and tapered fluidized beds with and without internal baffles. They reported the extent to which the quality of separation was affected by different operating and geometric parameters, namely gas velocity, feed composition, SFR, reflux, geometry of fluidization section, feed position, and internal baffles.

Tanaka, Koga, Akiyama, Shinohara, and Ishikura (1972) and Tanaka, Shinohara, Hirosue, and Tanaka (1972) studied the elutriation of fines from a continuous fluidized bed, and assessed the effects of gas velocity, SFR, feed composition, and particle size distribution of the fines. Besides those operating parameters, they also considered the effect of the overflow pipe. Furthermore, they examined the effects of fluid (air and water) properties, gas velocity, SFR, fines in feed composition and particle size distribution of fines along the column height on the elutriation of fines from both a continuous and a batch fluidized bed. Saksena and Mitra (1975) studied the classification of homogeneous powder in a fluidized bed. They

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assessed the effects of gas velocity, feed rate, and diameter ratio of two components, and they developed correlations for the enrichment and stripping factors. Valentine (1977) studied continuous separation of a binary mixture (fissile and fertile) in a gas–solid fluidized bed, examining the effects of gas velocity, SFR, feed-point location and aspect ratio, and separation of the fissile and fertile fuel particles to 99% of pure flotsam and 96% of jetsam particles was demonstrated.

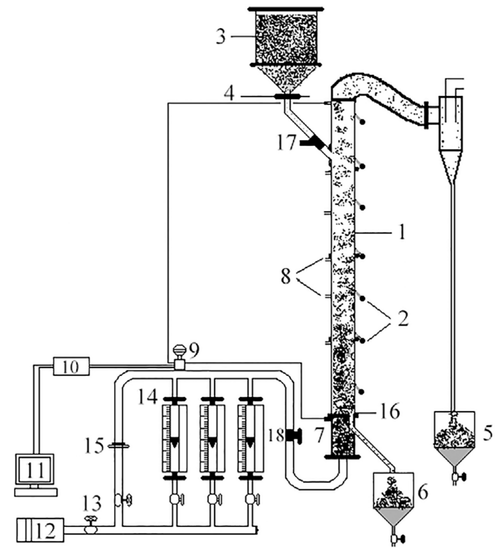
Barari, Kar, and Gupta (1978) studied the effects of particle size, particle density, gas velocity, SFR, feed composition and position on the continuous classification of a heterogeneous mixture in both up-flow and down-flow fluidized beds. They found that the separation efficiency depended on the product grade and the quality of the products. Kumar, Chandra, and Rao (1981) experimented with a continuous gas–solid fluidized bed to assess the effects of gas velocity, feed composition and the position of the top outlet on the classification performance, and proposed empirical correlations for the enrichment and stripping factors to predict the performance of the classifier. Palappan and Sai (2008a, 2008b, 2008c, 2010, 2011) studied the effects of particle density, particle size and feed entry on the segregation of a binary mixture of solids in a continuous fast-fluidized bed (FFB) in terms of axial solids holdup and axial solids concentration, thereby quantifying the performance of the segregator.

A careful survey of the literature on separation studies in FFBs reveals scant information about the quality of the product (purity) and the separation factor (recovery) in continuous separation, two important measures of the separation in a unit. Furthermore, no correlations are available for predicting product purity and recovery. Hence, in the present study, we investigate the continuous segregation of a binary mixture of solids in an FFB with the aim of measuring the solids holdup, separation factor and product quality. We investigate experimentally the parameters that affect the separation, namely the gas velocity, solids flow rate in the feed (SFR_{feed}), feed composition and density ratio. Because the height of the feeding position is an important variable, we determine an optimum height. We also develop empirical correlations for the separation factor and the product quality of the flotsam at the top outlet.

Experimental

A schematic diagram of the experimental setup of our continuous fluidized-bed separator is shown in Fig. 1. The experimental setup consists of a fluidized bed in an acrylic column with an internal diameter of 69 mm and a height of 3.76 m. A perforated distributor plate with a free open area of 13% (2-mm perforation diameter with 5-mm triangular pitch) was used to distribute the gas uniformly. A fine mesh was fixed to the perforated plate to prevent particles from flowing through the distributor plate.

The binary heterogeneous solid mixture to be separated was fed continuously under gravity from the hopper into the column at a height of 2.2 m above the distributor plate. A pre-calibrated perforated sliding scale was attached to the end of the hopper to regulate the SFR_{feed}. Calibration was done independently for each mixture and each perforation. To prevent the sliding scale from causing fluctuations in the SFR associated with the pressure inside the column, the top portion of the hopper was sealed to avoid any gas leaks. The top exit was connected to a cyclone separator, and was connected directly to the top product-collection tank. The overhead product from the fluidized bed that was separated by the cyclone separator was collected in the top collection tank, from which the entrainment rate could be obtained. We used a bottom discharge pipe with a diameter of 12.2 mm, which we connected directly to the bottom product-collection tank. The gangue particles that were separated



1. Fluidization section
2. Sampling ports
3. Solid feed tank
4. Sliding scale
5. Top collection tank
6. Bottom collection tank
7. Distribution plate
8. Pressure taps
9. Differential pressure transducer
10. Data-acquisition system
11. Computer
12. Compressor
13. Pressure regulator
14. Rotameter
15. Orifice meter
16. Bottom sliding scale
17. Ball valve
18. Solenoidal valve

Fig. 1. Schematic diagram of experimental setup of continuous fast-fluidized-bed separator.

in the fluidized bed fell under gravity into the bottom collection tank, from which the discharge rate could be obtained.

Air as a fluidizing medium was introduced at the bottom of the column from the compressor, pressure regulator, calibrated rotameters, and solenoidal valve. To distribute the air uniformly, we packed glass beads (2–3 mm in diameter) between the distributor plate and the air inlet. The pressure drop across the bed was measured using two pressure taps, one below the distributor plate and the other at the top of the column. A differential pressure transducer connected to a data-acquisition unit recorded the pressure drop continuously. The data-acquisition unit consisted of a personal computer equipped with a 12-bit analogue-to-digital data-acquisition board that sampled at a rate of 10 Hz.

In a typical experiment, gas was introduced from the bottom of the column through the distributor section at a specified flow rate after choosing a particular feed composition and system, and solids were introduced into the bed through the hopper at a specified flow rate. At the same time, the data-acquisition system began monitoring the pressure drop across the fluidized section. The experiment was carried out until a steady state was reached, which could be ascertained from the time variation of the pressure drop as shown in Fig. 2, and also by checking the material balance between the feed and outlet streams. Samples were collected from the top and bottom discharges, and the holdup of solids was collected by shutting down the inlet solid feed, bottom outlet and gas inlet simultaneously. The batch elutriation method was used to analyse the collected samples and holdup of solids for flotsam composition; this involved using a small fluidized bed and the float-and-sink method. The ideal separation of samples in both the batch elutriation and float-and-sink methods were in good agreement, with clear separation. This procedure was repeated for various gas velocities, SFRs, feed compositions and different system combinations. The physical