Particuology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Particuology

journal homepage: www.elsevier.com/locate/partic

Continuous segregation of binary heterogeneous solids in fluidized beds

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A R T I C L E I N F O

Article history:
Received 14 August 2015
Received in revised form 25 February 2017
Accepted 6 May 2017
Available online xxx

Keywords:
Normal fluidized bed
Continuous segregation
Heterogeneous particles
Separation factor
Holdup

A B S T R A C T

Continuous segregation of a binary mixture of heterogeneous (different density) solids is carried out in a gas–solid fluidized bed. We investigate how gas velocity, solids feed rate, flotsam feed composition, bottom discharge pipe diameter, and minimum fluidization velocity ratio of the flotsam to jetsam particles influence the solids holdup, separation factor, and product quality (flotsam purity at the top outlet). The results are interpreted in terms of solids holdup information. The results indicate that the separation factor decreases when the gas velocity, bottom discharge pipe diameter, flotsam feed composition, or the minimum fluidization velocity ratio increase, while the separation factor increases as the solids feed rate increases. The product quality decreases when the gas velocity, solids feed rate, or minimum fluidization velocity ratio increase, while the product quality increases as the bottom discharge pipe diameter or flotsam feed composition increase. Correlations for predicting the separation factor and product quality are proposed using a logistic model for individual flotsam feed compositions, which satisfactorily compares with the present experimental data.

Introduction

Segregation is a process in which a mixture of solid particles of different species becomes spatially non-uniform through self-sorting by size and/or density. Segregation of binary mixtures of solid particles based on size difference (homogeneous/equal density mixtures) and/or density difference (heterogeneous/different density mixtures) is one of the important activities in many chemical and metallurgical process industries. The applications include separation of valuable minerals from gangue, washing out coal dust, or separation to various size fractions. A variety of equipment is being used for segregating particles in which the behavior of the material is influenced to a greater degree by physical properties such as size, density, and shape. Equipment selection depends on the physical properties of the material, the nature of the product, and the economics of the process.

The fluidized bed classifier is one possible apparatus used for separation of particle mixtures. The inherent properties of particle segregation in the fluidized bed can be advantageously used to classify particles of different sizes and/or densities. One of the main reasons particles segregate in gas–solid fluidized beds is that the particles are subjected to an imbalance of forces such as drag and gravity, which arise during periodic disturbances associated with the passage of bubbles and due to the differences in size and/or density. The forces which promote segregation in fluidized beds have been discussed by Sutherland and Wong (1964). During fluidization, however, particle mixing forces overcome particle segregation forces and more or less uniform solid phase results under normal operating conditions. These forces are much larger in the case of liquid fluidization than in gas fluidization. In such systems, a dynamic equilibrium is established between the competitive mechanisms of mixing and segregation. This leads to a variation in solid composition over the height of the bed, with some components tending to rise and others tending to sink. Hence only the fluidized beds are under the extreme conditions of normal/bubbling fluidization (fluidized beds operating near the minimum fluidization gas velocity of heavier component) when mixing is at its minimum and segregation effects are noticeable at elutriation level. The component which tends to segregate and float to the surface of the bed (lighter/fine) is called *flotsam* whilst that which tends to sink (heavier/coarser) is called *jetsam* (Rowe, Nienow, & Agbim, 1972).

The advantages of using fluidized beds for segregation of particles are given by Adham (2001). Some of them include product consistency, construction and operation simplicity, and mainte-

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http://dx.doi.org/10.1016/j.partic.2017.05.004
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Please cite this article in press as: Prasad Babu, M., et al. Continuous segregation of binary heterogeneous solids in fluidized beds. *Particuology* (2017), http://dx.doi.org/10.1016/j.partic.2017.05.004

nance ease. Compared to other processes, fluidized beds also have less breakdown time due to the absence of moving parts, considerable reduction in layout space, and less separation time. The air required is also less in a normal fluidized bed compared to wind sifting or other competing processes. Fluidized beds are widely used in process industries such as coal combustion, mineral processing, waste recovery, and agriculture.

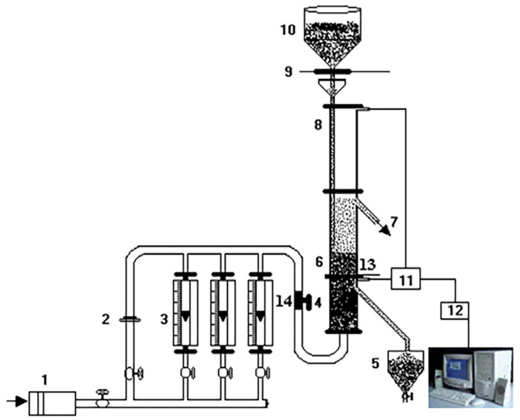
A large number of studies of particle segregation in batch fluidized beds have been reported in the literature. However, not much attention has been focused on the segregation of particles with continuous feed, top (flotsam, light/fine) and bottom (jetsam, heavy/coarser) discharge of the particles.

Capes and Sutherland (1966) studied the effect of gas velocity, solids flow rate, bed height, location of the feed point, and withdrawal of the bottom product on segregation of heterogeneous solids (germanium, hematite, and magnetite ore) in continuous and batch packed fluidized beds. They noted that both purity and recovery decrease as the gas and solids flow rates increase, and increase as the aspect ratio and feed position increase. Naveh and Resnick (1974) investigated homogeneous mixture segregation of continuous size distribution of solids in baffled fluidized beds in batch and continuous operation, with and without side-stream air withdrawal, at different gas velocities, solids flow rates, and feed locations. A new term, the "segregation index", was developed which permits a comparison between batch-wise and continuous separation. They developed an empirical correlation for segregation index in terms of operating variables of dimensionless groups.

Baskakov, Malykh, and Shishko (1975) studied the effect of gas velocity, packing material in the distribution section, minimum fluidization velocity ratio, and product discharge method on the separation of heterogeneous material into a rectangular sectioned fluidized bed with continuous charging and discharging. They proposed equations for optimum gas flow rate for both sections (top and bottom section). Beeckmans and Yu (1992) investigated the effect of stirrer rotation, gas velocity, and solid feed rate in a continuous mechanically fluidized bed using both two- and three-component systems. They noted that stirring increases separation quality up to a certain limit, but the separation quality then declines as the effects of increased bubble-induced mixing overcome the beneficial effects of improved fluidity. Chyang, Wu, and Ma (2002) studied the effects of gas velocity, baffle spacing, screen size, feeding location, feeding rate, and bed height on particle segregation of homogeneous mixtures in a continuously-screened, baffle-packed fluidized bed.

Palappan and Sai (2008a, 2008b, 2008c, 2010, 2011) investigated the effects of particle density, particle size, and feed entry location on segregation of binary solid mixtures in continuous fast fluidized bed in terms of solids holdup, axial solids holdup, and axial solids concentration, and quantified the performance of the segregator. Their analysis of the experimental results showed that the nature of the influence of process parameters on the sharpness of separation is identical for mixtures of granular materials and mixtures of liquids. They presented velocity–composition phase diagrams for the flotsam and the jetsam phases in equilibrium and highlighted some contradictory observations of the size segregation of solids compared with density segregation.

In the present work, continuous separation of binary heterogeneous mixtures is carried out in a fluidized bed without any screens or packing material and the results are presented in terms of separation factor and product quality using mean residence time information. Those operating and design parameters of the present study that affect the separation are gas velocity, solids feed rate, flotsam feed composition, bottom discharge pipe diameter, and minimum fluidization velocity ratio of the flotsam to jetsam particles. No studies have reported the effect of bottom discharge pipe diameter yet, to the best of the knowledge of the authors, although it plays an important role in the separation studies.



1. Compressor
2. Orifice meter
3. Rotameters
4. Packed bed
5. Bottom product collection tank
6. Defluidized jetsam layer
7. Top product outlet
8. Vertical stand pipe
9. Sliding scale
10. Solids feed tank
11. Differential pressure transducer
12. Data acquisition system
13. Bottom slide scale
14. Solenoidal valve

Fig 1. Schematic of the experimental setup.

Experimental

A schematic diagram of the experimental setup of the continuous fluidized bed separator is shown in Fig. 1. The experimental setup comprises a fluidized bed made from an acrylic column with an internal diameter of 69 mm and a height of 3.76 m. For uniform air distribution, a 30 cm high distribution section packed with 2–3 mm diameter glass beads was provided between the distributor plate and air inlet. A perforated distributor plate with a free open area of 13% (2 mm perforation diameter with 5 mm triangular pitch) was used and a fine mesh was fixed to the perforated plate to prevent particle flow through the distributor plate. A bottom discharge pipe with the ability to vary the diameter was used. This pipe was directly connected to the bottom product collection tank. A 25 mm diameter overflow pipe was provided at a height of 23.5 cm from the distributor plate to withdraw the top product.

Air as a fluidizing medium was introduced at the bottom of the column from the compressor, pressure regulator, calibrated rotameters, and a solenoidal valve. The binary heterogeneous solid mixture to be separated was fed continuously under gravity flow into the bed from a hopper through a precalibrated slide scale at the top of the column. Two pressure taps were used to measure the pressure drop across the bed, one below the distributor plate and the other at the top of the column. The pressure drop was continuously recorded by a differential pressure transducer connected to data-acquisition unit and displayed on the monitor. The data-acquisition unit consists of a PC equipped with a 12 bit A/D data acquisition board at a rate of ten samples per second.

The samples collected from the experiment were separated in a batch elutriator. The batch elutriator consists of a fluidized bed of 56 mm internal diameter and a height of 100 cm made of acrylic column. Batch solids (samples) to be separated were fed into the column through a hopper and the top portion of the fluidized bed was directly connected to the cyclone separator for separating the gas solid mixture. The physical properties of the materials used in the present study are shown in Table 1.

In a typical experiment, a particular gas flow rate was introduced from the bottom of the column after choosing a particular feed composition, bottom discharge pipe diameter, and system. A specified

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