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Density-based separation in a vibrated Reflux Classifier with an air-sand dense-medium: Tracer studies with simultaneous underflow and overflow removal

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A B S T R A C T

The continuous separation of tracer particles in the air-sand dense-medium Reflux Classifier was investigated. The Reflux Classifier consisted of a 1 m long vertical fluidized bed section with a 2 m long channel inclined at 70° to the horizontal mounted above, both with a 20 × 100 mm cross section. Silica sand of 220 μm average diameter (−355 + 125 μm) was used as the dense medium. The Reflux Classifier produced good density separations for tracer particles ranging in size from 6.35 down to 1.0 mm. The density cut-point could be varied from 1418 to 2130 kg/m^3 by varying the underflow rate and the *Ep* was within the range of 0.06–0.46 × 10^3 kg/m^3 depending on particle size and gas rate. At certain gas flowrate and underflow conditions the density cut point ranged between 1534 and 1619 kg/m^3 across six particle sizes, suppressing the effects of particle size on the density cut point. As air rates increased from 4.03 to 5.64 × 10^{-4} m^3/s the density cut-point increased, as did the *Ep*. The results were compared with separations in a vertical fluidized bed of the same total length. *Ep* values in the vertical fluidized bed ranged between 0.07 and 1.49 × 10^3 kg/m^3 over the same experimental conditions as the inclined bed and the density cut point showed more variability with the conditions. The addition of an incline above the fluidized bed provides a more stable system allowing for greater separation efficiency and minimizing the effect of changing conditions. Increasing the flow of sand medium to the underflow decreased the density cut point while raising the gas rate increased the density cut point. Raising the gas rate also increased the variability of the system which resulted in a lower separation efficiency.

1. Introduction

Run-of-mine coal consists of combustible carbon based material and non-combustible mineral matter, commonly referred to as ash, which is typically composed of silica based material. Often, before it can be utilized to produce energy or metallurgical coke, the coal must be beneficiated to remove much of the non-combustible material. A typical coal beneficiation process involves breaking the coal to pass a 50 mm screen before classifying into three parallel streams. The coarse stream is separated on the basis of density in dense medium cyclones, the fines are beneficiated in spirals and the ultrafines via flotation (Sanders, 2007). All three of these processes are water based and thus coal is traditionally only mined in areas that have a good water supply. The final wet coal product then must be dewatered to meet contractual moisture levels.

The efficiency of water based processing is undeniable, with near ideal density based separations achievable. Water processing is, however, not without disadvantages. In particular, the product is moist, and thus has a lower calorific value. Water beneficiation processes require significant infrastructure for tailings disposal and water recovery processes such as filters, centrifuges and thickeners.

Australia is the fourth largest coal producer in the world and the largest exporter. It is also the driest inhabited continent on Earth. As the reliability of water in many mining regions decreases interest in dry beneficiation methods for coal is increasing. In addition to not needing a reliable water supply, a dry beneficiation process provides a dry coal product which has a higher calorific value and lower transport costs than coal that has been beneficiated in water based processes. Some potential disadvantages of dry coal processing when compared to water processing include an increased need for dust controls, the risk of explosion of coal fines and a need for a dry feed.

The use of the Reflux Classifier for the dry beneficiation of coal has already been reported by these authors with reference to the performance of a batch system with no underflow stream (Macpherson et al., 2010). This work is a continuation of that previous study, extended to a system with continuous underflow and overflow removal. The effects of the underflow rate and the gas flow rate on the density cut point and separation efficiency are investigated.

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2. Experimental

The apparatus used for the continuous separations was a modification of that used by Macpherson et al. (2010) for batch separations. The main apparatus including the inclined and vertical fluidized bed sections remained the same, as did the springs and motors. The fluidized sections were constructed of stainless steel and consisted of a 1 m vertical section and 2 m inclined section each with a 20 × 100 mm cross-section. The apparatus was vibrated linearly by a pair of motors and the whole frame was mounted on four springs for vibration isolation. This is illustrated schematically in Fig. 1.

To allow for simultaneous solids removal and fluidization gas addition at the bottom of the Reflux Classifier (RC), the gas distribution system was modified. A new flanged channel section was constructed with the channel walls forming the distributor plate. 20 × 1 mm diameter holes were drilled into the channel walls and surrounded by a plenum chamber to form the gas distributor. This gas feed system was bolted below the 1 m vertical bed and was found to provide the same bubbling pattern as the batch plenum chamber and distributor plate, while leaving a packed bed beneath the gas inlet holes as long as there was no path for the air to escape below.

Below this new gas distributor the bed was constricted through a pyramid shaped channel into a 25 mm round hole where a pair of 25 mm pneumatic pinch valves (*AKO Armaturen and Separations GmbH*, DN025) were attached in series to control the underflow rate. The manual feed valves were also replaced by a pair of 50 mm pneumatic pinch valves (DN050) to allow for automation of the feed. The pinch valves alternated opened and closed in order to allow solids flow but minimize escape of air from the bed. The timing of valve opening and closing could be varied to give whatever solids rate was desired.

Samples of plastic tracer particles (*Partition Enterprises*, Queensland) described by the manufacturer as 'naturally shaped' with densities of 1300, 1600, 1800, 2100 and 2400 kg/m^3 were prepared in the size fractions −6.35 + 5.6, −5.6 + 4.0, −4.0 + 2.8, −2.8 + 2.0, −2.0 + 1.4 and −1.4 + 1.0 mm with the number of particles of each size fraction ranging between 50 for the largest and 200 for the smallest particles in each batch. These size fractions were combined into their density fractions as one sample.

To commence an experiment, the bed was filled with sand (*Unimin Australia*, 50 N screened to −355 μm) and then the gas and vibration switched on. After any excess sand had been elutriated, feeding of sand and underflow removal was commenced. In all of the experiments the sand feed rate was 560 g/min and the vibration rate was 595 rpm in the vertical plane. Further discussion of the vibration can be found in Macpherson (2011). Once a consistent overflow of sand was established, a sample of one density of tracers (all size fractions) was fed into the bed with sand so that the volume of the feed was consistent throughout the run. At this point samples of the overflow and underflow were taken at three minute intervals. The remaining samples of tracer particles were added one density at a time at 10 min intervals. Adding the particles one density at a time made it easier to separate them at the end of the experiment. Sand continued to be fed at regular intervals and samples at the overflow and underflow taken every three minutes until there were only very few particles exiting in each time interval (approximately 2 h).

The air rate was varied between 4.03 and 5.64 × 10^{-4} m^3/s and the underflow rate between 260 and 460 g/min. The air rate was measured using a gas rotameter in % of maximum flow. A flow rate of 4.03 × 10^{-4} m^3/s corresponded to 25% of maximum flow. Experimental results are reported in terms of the rotameter reading for simplicity.

Each overflow and underflow sample was screened at 710 μm to remove the sand and any tracer particles in the stream were then further sieved into their size fractions. These were then sorted and counted to determine the number of each size and density of tracer particles that was in the sample.

The experiments done in the Reflux Classifier were repeated in a vibrated vertical fluidized bed (Fig. 2) in order to determine the ef-

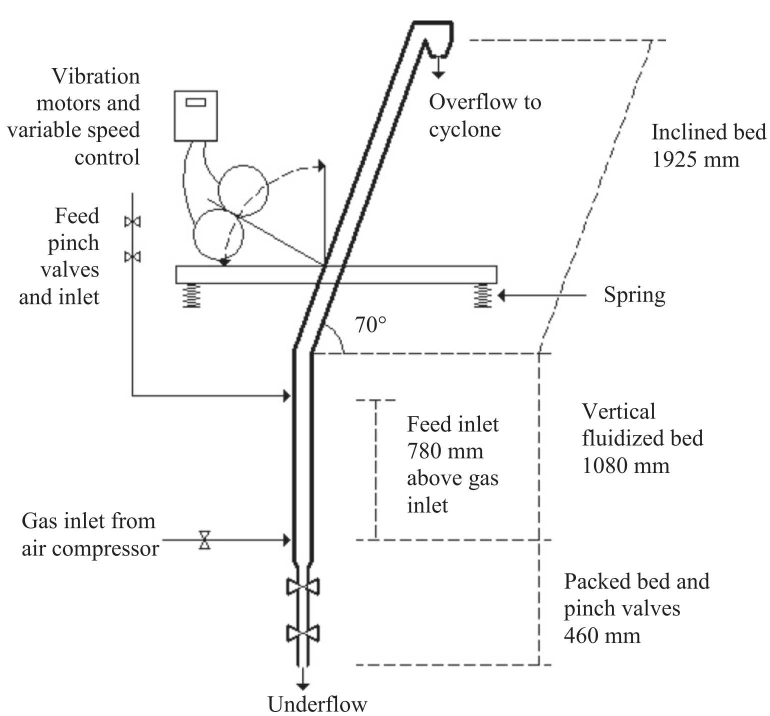

Fig. 1. Schematic of the continuous Reflux Classifier apparatus showing the main vertical and inclined channel, the gas and feed inlets and the attached vibratory motors and underflow double pinch valves.