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Fluidized Bed Dry Dense Medium Coal Beneficiation

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Abstract— Coal beneficiation in South Africa is currently conducted mostly on a wet "float and sink" basis. This process is heavily water intensive and also potentially polluting. Dry beneficiation alternatives are being sought. The alternative of dry dense medium beneficiation using a fluidized bed was investigated. Bed materials of sand, magnetite and ilmenite were used in a laboratory sized cylindrical fluidized bed. The materials were individually tested, as were mixes of sand and heavy minerals. Coal particles were simulated using vials of varying density.

The sand experiments proved that dry beneficiation is feasible, and with the addition of heavier components the point at which coal can be split can be altered. The experiments with magnetite were unsuccessful, whereas ilmenite proved successful. This should however not eliminate magnetite as a viable option and it must be further investigated before an economic study is conducted.

The experimental programme and results are discussed and presented.

INTRODUCTION

Coal beneficiation is the process by which the combustible fraction of coal is separated from inert (ash) material to produce a product of improved properties, generally with a higher calorific value (CV). The principle of this separation is that the combustible fraction has a lower density than the ash fraction, and treating the coal in a medium of a certain density will cause the lighter material to float and the heavier material to sink. Conventionally, this is carried out using a water-based slurry of magnetite. This process is however water intensive. Much of the remaining coal reserves in South Africa are located in water-stressed environments such as the Waterberg[1]. Therefore a new process is required to reduce the water usage while achieving the same yields.

The desired process is one that can separate particles according to density, while lowering the dependency on water. Fluidized bed technology is a potential solution[2]. In a fluidized bed solid particles are suspended in air, causing the bed to exhibit many of the properties of a fluid. The bed material used determines the density of the bed.

The aim of this investigation was to determine if a fluidized bed can separate solid particles by density and if the bed medium can affect the observed split in density. This was done using fluidized beds with different media to change density and testing multiple parameters to attain a better understanding of how the density split could be controlled.

EXPERIMENTAL

Materials/Media

Sand

Silica sand is an oxide of silicon with the formula SiO_2. It is a very abundant and cheap material available in a wide range of particle size distribution (PSD) and sphericity. The starting bed material in Fluidised Bed Combustors (FBC) is generally silica sand. Sand was used as a "proof of concept", to see if separation by density could be achieved in a fluidised bed. However, it was expected that due to sand's measured Specific Gravity (SG) of 2.6 and voidage of approximately 0.5, sand alone could not be used for coal beneficiation. The density of the fluidised bed would be below density of interest. Sand with a size range between 75 microns and 300 microns was sourced from Rolfes Silica in Brits.

Magnetite

Magnetite is one of three naturally occurring iron oxide minerals. It has magnetic properties and a high SG of 5.5. The particle size and shape however causes magnetite to have fluidising difficulties. This is because of clumping behaviour which is the result of its magnetic properties and jagged particle nature. Magnetite with a d_{50} of 100 microns was sourced from a company in the Witbank area. This is a by-product of a Vanadium production process.

Ilmenite

Ilmenite is a titanium iron oxide mineral with the chemical formula $FeTiO_3$. It is the world's most important titanium bearing mineral. The interest for Coal beneficiation lies it its relatively high reported specific gravity of 4.7 to 4.79. This high SG together with the smooth pebble-like nature of ilmenite makes for a very good bed medium. Ilmenite is also proven to be slightly magnetic, which can aid in separation processes.

Apparatus

The experimental work was undertaken in a 150mm diameter Perspex fluidised bed. Fluidising air was provided by a fan/blower. The volume of the air was controlled by a gate valve and measured using an orifice plate and manometer. The pressure drop over the distributor plate and bed, and the pressure drop over the bed, were measured by manometers. The apparatus can be seen in figure 1.

Figure 1. Experimental apparatus

Tracers ("artificial" coal particles of various densities) can be purchased. For these tests, however, tracers were made up from small plastic vials. These vials had a total volume of 14 ml. They were filled with sand and other materials to create particles of varying densities, from an SG of 1.2 up to an SG of 2. Some of these can be seen in Figure 2.

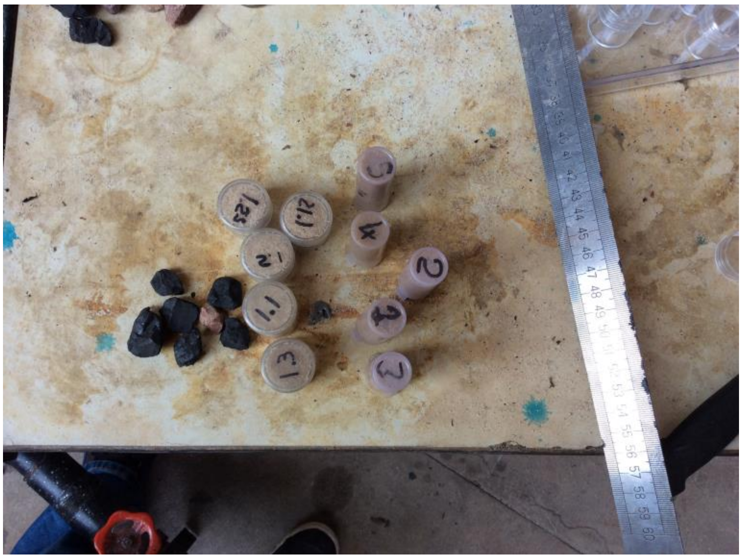

Figure 2. Tracers

An initial thought was that a fluidising velocity close to the minimum fluidising velocity, U_{mf} (i.e. a "quiescent bed") might produce the most repeatable results. It was found, however, that little or no segregation occurred at these low velocities. Repeatable results were obtained at a velocity of about 3 times U_{mf}. All experiments were thereafter conducted at this multiple of U_{mf}.

For the sand bed experiments, the bed was fluidised and the tracers added. After one minute the particles floating on top were removed, and then the particles that had sunk to the base of the bed were removed. The split point was taken as between the heaviest tracer that floated and the lightest tracer that sank.

The intention with the magnetite bed was to compose a bed of pure magnetite, and then beds of an increasing proportion of sand with the magnetite. However, operational problems, reported in the Results section below, meant that this plan could not be followed.

For the ilmenite bed experiments, beds of pure ilmenite and increasing proportions of sand were used. The tracers were again used to determine the split point.

(1)

RESULTS AND DISCUSSION

Initial experiments with sand only fluidised beds proved the feasibility of separating larger particles based on the particle density.

The tracers were dropped into the fluidised bed. It was found that the sand bed split particles at a density between 1.25 and 1.35 kg/l. This was a counter intuitive result since a bubbling fluidised sand bed has a bed density of around 1.1 kg/l compared to the bulk density of 1.3 kg/l. It would therefore appear that the bed splits at the media's bulk density rather than the observed or calculated fluidized density.

Since the sand bed proved the feasibility of dry beneficiation, a new material was introduced. Magnetite is the media used currently in wet coal beneficiation systems. It is relatively abundant, cheap and can be separated from the coal product magnetically. The industry is use to working with magnetite and its use in dry systems could help facilitate adoption of such systems. For the experiments a sample of Magnetite was used with a very small average particle diameter. The d50 was 100 microns.

Attempts to fluidize the magnetite sample were unsuccessful, after investigation under microscope it was found that although the magnetite is regarded as a Group B sand-like particle by Geldart's classification[4], it behaved more like a Group D particle and would not fluidize. Even after the addition of sand as a diluent, the magnetite tended to clump together in groups much larger than the parent material. To determine why the sample of magnetite behaved as it did, microscopic images where taken. Two of these are shown in Figure 3.

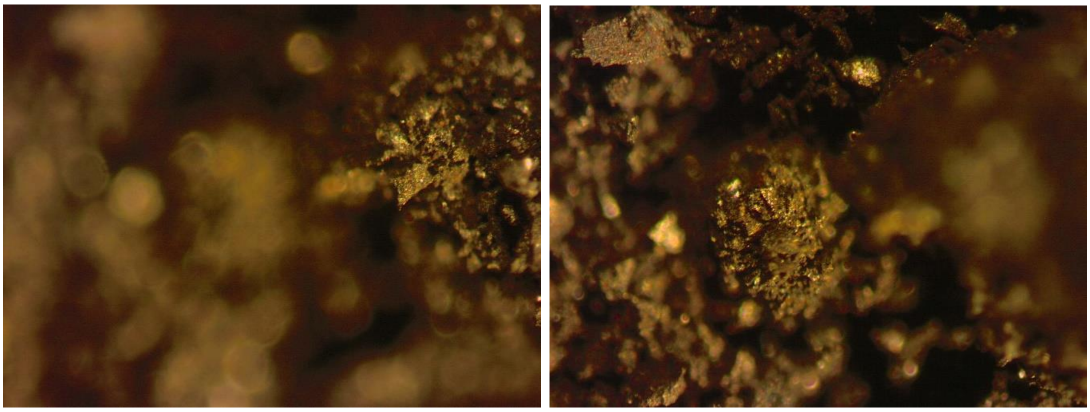

Figure 3. Optical microscope images of the magnetite sample

The image on the left of figure 3 illustrates a spire or strand seen across the entire sample. These spires are clumps of finer magnetite particles which agglomerate because of magnetic forces. Because of this clumping behaviour, the fluidizing gas cannot break the particles apart and essentially increased the PSD of the magnetite and made it behave as Group D particles.

It was decided to discontinue the experiments with magnetite as a medium.

The final material evaluated as a bed medium was ilmenite. The ilmenite was investigated under microscope to determine its particle behaviour. The images are shown in Figure 4.

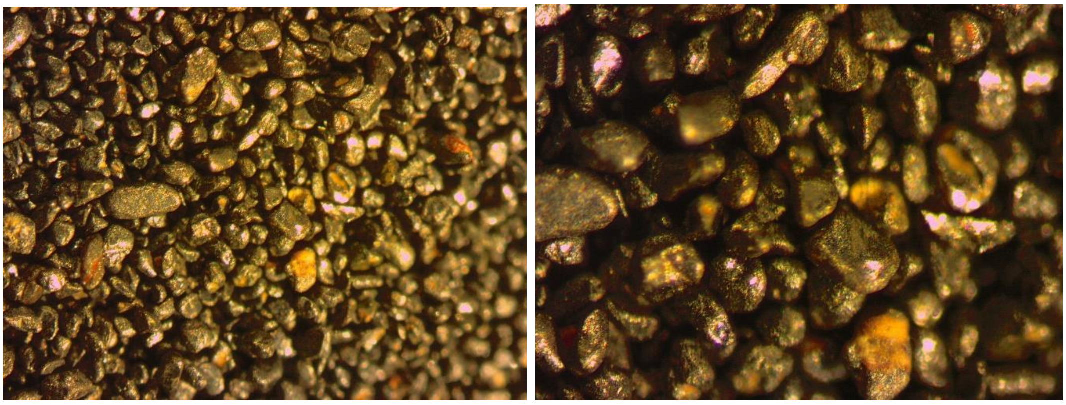

Figure 4. Optical microscope images of the ilmenite sample

As seen on these images the ilmenite has a very different shape and behaviour as compared to the magnetite. This material is more sand like and has a higher sphericity than the sand sample used. Since the microscopic results were promising, a sample of ilmenite with a d50 of 125 microns was fluidised at a bed height of 120 mm for an L/D of 0.8. The resulting bubbling fluidization was as expected and provided a split, with pure ilmenite, of 3.0 kg/l to 3.1 kg/l.

This was an interesting result since the calculated true density of ilmenite was found to be 4.8 kg/l, which would imply a bulk density of 2.4 at a voidage of 50%. The experimental results indicated a bulk density of 3.05 kg/l which suggested a voidage of 36%. Since this observed split was heavier than the suggested split range of 1.2 kg/l to 2.5 kg/l for coal separation in South Africa, mixes of sand and ilmenite where tested. This was done to determine a density split to sand % correlation that could be used for future work.

The sand was gradually added to the ilmenite and the procedure explained in the Experimental section was carried out. The mixture was adjusted to keep an L/D ratio of between 0.8 and 1.

The results of these experiments are shown in Table 1. It can be seen that the previously observed trend for the density split to occur at the bulk density hold true for the sand-ilmenite mixtures. The predicted density was calculated using the bulk densities and mass fractions of the two materials. This however differed from the real observed bulk density in column 4. The fluidised density is always lower as expected. The split however always remained closer to the real bulk density.

Table 1. Density split at varying sand/ilmenite ratios

Sand %	Obs U_{mf} (m/s)	Predicted ρ_{bed} (kg/l)	Real ρ_{bed} (kg/l)	Fluidized ρ_{bed} (kg/l)	Observed split (kg/l)
0	0.029	2.80	2.82	2.78	3.00
8	0.030	2.56	2.66	2.45	2.75
15	0.030	2.39	2.51	2.34	2.60
28	0.030	2.12	2.19	2.05	2.30
33	0.031	2.03	2.15	1.89	2.25
40	0.033	1.93	2.07	1.86	2.05
45	0.037	1.85	2.00	1.77	1.95
53	0.037	1.75	1.80	1.59	1.75
58	0.037	1.69	1.71	1.56	1.65
75	0.037	1.52	1.61	1.37	1.45
80	0.052	1.47	1.49	1.28	1.4

The observed split was plotted against the sand% added to the mixture. The resulting graph is shown in Figure 5. The results provide a good trend between the split density and the sand % which can be seen on the blue curve. The curve contains some experimental anomalies which could be attributed to a number of possible errors in the makeup of the bed, or the density of the tracers. The green line represents a trendline fitted linearly which results in a R^2 value of 0,976.

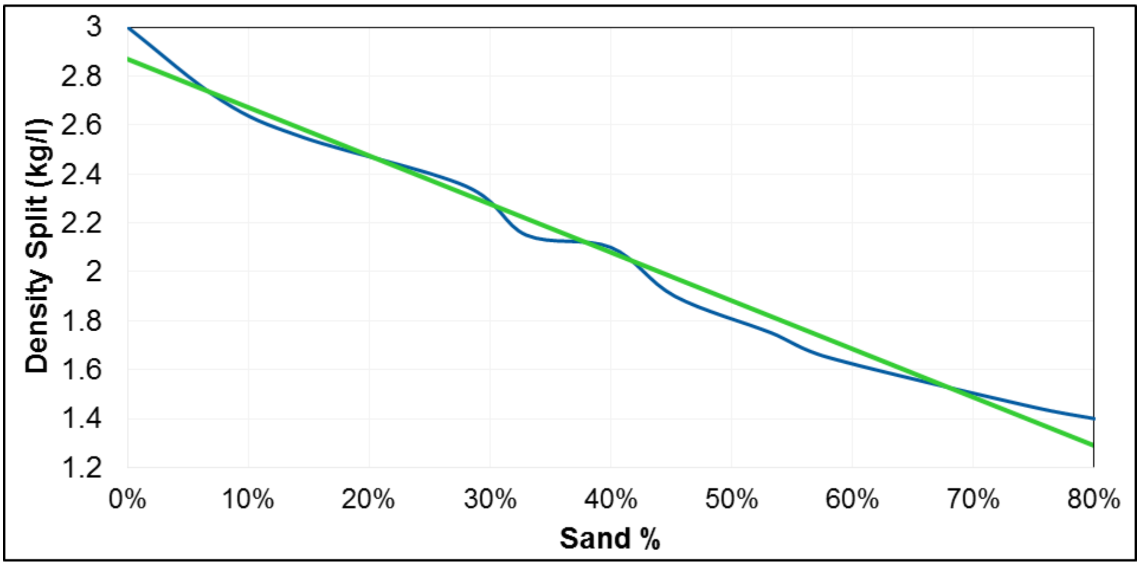

Figure 5. Density split at varying sand/ilmenite ratios

CONCLUSIONS AND RECOMENDATIONS

The research has proven the feasibility of dry coal beneficiation using a fluidized bed.

The results from magnetite were disappointing, as the magnetite did not fluidize. It clumped together due to magnetic attraction. Subsequent to the research being carried out it has been learned that the magnetite could be demagnetised. It is recommended that further experiments be carried out using demagnetised magnetite, as there are benefits for using magnetite as the medium as indicated in the paper.

The results from ilmenite were promising for an alternative to wet coal beneficiation, with a clear trend in density split with sand/ilmenite ratio being seen. There are some anomalies in the trend. It is recommended that further experiments be carried out with commercial tracers, to remove this as a possible source of error. It is further recommended that the experiments be repeated on a larger experimental rig, this would eliminate effects from the limited L/D ratio of the equipment used and possible wall effects on tracers.

Sand was used as a diluent to reduce the bed density in the experiments. Other materials could be considered. In particular, coal fines should be investigated.

The tracers used in the experiments were representative of relatively large or pea-sized coal particles. The ability of a fluidised bed to split smaller coal particles should be determined.

For a commercial plant, a bed management system will need to be devised, to maintain the bed at the correct composition, density and PSD.

Methods of separating the medium from the coal need to be investigated.

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ACROYNYMS/ABBREVIATIONS/NOMENCLATURE

CV	Calorific Value
FB	Fluidised Bed
FBC	Fluidised Bed Combustion/Combustor
L/D	Bed depth to diameter ratio
PSD	Particle Size Distribution
SG	Specific Gravity
U_{mf}	Minimum Fluidizing Velocity

GREEK SYMBOLS

ρbed	Bed bulk density	kg/m3
ρp	Particle density	kg/m3
ρf	Gas density	kg/m3

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