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The role of viscosity in the density fractionation of particles in a laboratory-scale Reflux Classifier

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HIGHLIGHTS

- Glycerol solutions improve the density-separation performance of Reflux Classifiers.
- The key to good separation is laminar flow in narrow channels with high shear rates.
- 50% Glycerol solution was optimum for particles in the 0.25–2.0 mm size range.
- 70% Glycerol solution was optimum for 2.0–16.0 mm coal particles.
- The laboratory Reflux Classifier can potentially replace the float-sink method.

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ABSTRACT

It is common practice in the coal industry to use heavy organic liquids to fractionate coal samples on the basis of density. However, concerns over worker health and the influence of these liquids on coal carbonisation properties are prompting the search for alternative water-based methods. Previous work has already shown that 0.038–0.25 mm samples can be very effectively separated using pure water in a Reflux Classifier with narrow 1.7 mm channels. Narrow channels give laminar flow with high shear rates which promotes density-based separation. Processing coarser particles requires wider channels and the laminar flow condition is lost, reducing performance.

This work tested whether using viscous glycerol solutions to restore the laminar flow condition could improve the separation performance of the laboratory Reflux Classifier for larger particles. For 0.25–2.0 mm coal particles, using 50 wt.% glycerol solution in 6 mm channels, the Reflux Classifier was able to match the float-sink yield-ash curve across the entire yield range. For 2.0–16 mm coal, using 70 wt.% glycerol solution in 24 mm channels, the Reflux Classifier gave results which were at worst only 1.0 wt.% ash units off the float-sink curve. Hence the Reflux Classifier can potentially replace the float-sink method for measuring the washability of small bore core samples and producing clean coal composites.

1. Introduction

The Australian Coal industry currently uses the float-sink method for washability analysis of coal samples and the preparation of clean coal composites for coke testing from small bore cores. The float-sink test is a density-based separation method which uses mixtures of heavy organic liquids. These organic liquids are expensive, hazardous and can also adversely affect the carbonisation properties of coking coals [1,2]. It is therefore desirable to develop a suitable replacement for the float-sink method. Small bore cores taken from a potential mine site are typically crushed down to a top size of 16 mm before being float-sink separated. Hence any potential replacement for the float-sink method needs to be able to effectively process particles up to a size of 16 mm.

The Reflux Classifier is a relatively new gravity separation unit that consists of a set of parallel inclined channels located above a conventional fluidized bed (Fig. 1). It has been the subject of much research and development during the last decade. The first benefit of the inclined channels compared to a conventional fluidized (teetered) bed separator is the increase in throughput due to the increased effective settling area provided by the channels, the so-called Boycott effect [3]. A second benefit of the inclined

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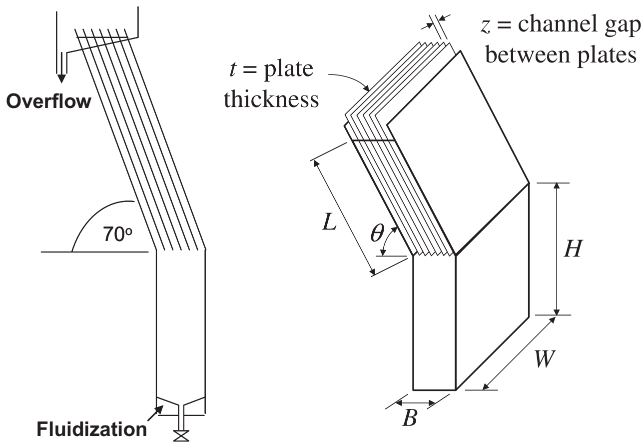

Fig. 1. (a) Side view of Reflux Classifier batch configuration and (b) cabinet-projection view showing definition of key dimensions.

channels is that low-density particles that settle onto the inclined surface are more likely to be re-suspended than high-density particles. This improves the efficiency of the device as a density-based separation process [4]. Recent work using narrow channels where laminar flow occurs has shown that the effects of particle size can be almost totally suppressed, particularly for particles in the transition settling regime [5–7].

In industrial processes, the Reflux Classifier is operated continuously, with feed added part way up the vertical section and fluidizing water at the base. An underflow of dense material is continuously removed from the base and the overflow of low-density material exits via the launder at the top. During continuous processes, a bed of near-density material builds up inside the unit, producing an autogenous dense-medium effect which further improves performance as a density separator.

For laboratory-scale separations, the Reflux Classifier is operated in semi-batch mode with no feed addition or underflow removal (Fig. 1a). An initial charge of particles is first placed in the vertical section. Then a flow of fluidization water is started from the base. The flowrate of fluidizing water is then increased in a number of steps. At each flowrate, the flow is held steady until the rate of particle elutriation becomes negligible. Initially low-density particles (and also fine slimes) are preferentially conveyed out of the system. As the flowrate is increased, particles of higher density (and also larger size) are successively elutriated. The particles elutriated at each flowrate are collected separately, weighed and analysed. These data can then be used to generate a yield-ash curve. This is a plot of the cumulative yield versus the cumulative ash content obtained when the samples are progressively combined in order of increasing ash content. Cumulative yield is the sum of the mass of each sample up to that point divided by the total mass of all the samples. Cumulative ash content is the sum of the mass of ash in each sample up to that point divided by the total mass of the sample up to that point [8].

The Reflux Classifier generated yield-ash curves have been shown to be in excellent agreement with conventional float-sink results for coal particles in the 0.038–0.250 mm size range. However, the dilute conditions involved in these semi-batch tests result in loss of the autogenous dense-medium effect and particle size has a larger influence. Hence in the 0.25–2.0 mm size range, although the separation is reasonable, the Reflux Classifier does not give as close a match to the float-sink results. A double fractionation step where each flow increment is screened into different sized sub-fractions for more detailed analysis provides strong improvement [9–11]. However, this double fractionation step requires the expense of screening and additional ash measurements, so it would be desirable to avoid it by finding a way to improve the initial separation performance in the Reflux Classifier.

Using the laboratory Reflux Classifier to process larger particles in the size range 2.0–16 mm is not only likely to be less efficient, but may also pose additional problems due to the considerably higher flowrates required to elutriate these particles from the system. The high turbulence associated with these high flowrates may also cause significant particle attrition, thus compromising the validity of the results.

One potential way to minimise these problems is to use a liquid of higher viscosity and density than water. Laskovski et al. [4] performed an experiment using 70 wt.% glycerol solution as the fluidization medium. This glycerol experiment required flowrates with a superficial velocity approximately 30 times lower than used in similar water-based experiments. Glycerol could therefore serve as a suitable fluidization medium for coarser particles, with the lower flowrates resulting in less attrition. Furthermore there is the added benefit that the flow in the channels is more likely to be laminar and that large particles are more likely to be settling in the transition regime. Both of these changes are likely to improve the efficiency of density separation [9].

This paper reports work done to test the effectiveness of using glycerol solutions in the Reflux Classifier to perform washability tests on particles in the 0.250–2.0 mm and 2.0–16 mm size ranges. The performance using water and glycerol solutions is compared to float-sink results. The theoretical basis behind the expected improvements using glycerol solutions is first explained in Section 2. The details of the experimental method are then given in Section 3. This is followed by the results and discussion in Section 4, and then some final conclusions.

2. Theory

Within an inclined section, particles have only a relatively short distance to fall vertically before they settle against the lower surface of the channel, from where they can slide *en masse* down to the base of the channel. This so-called Boycott effect [3] produces an increase in the effective settling area compared to a purely vertical column with the same footprint. Hence parallel inclined channels are beneficial in lamellae thickeners [12], offering very high hydraulic loadings. In such an application the objective is to simply capture all of the solids, often flocculated particles, onto the inclined surfaces, allowing clear supernatant to pass through. We may define the throughput advantage F of inclined channels as the ratio of the superficial upwards velocity of the fluid in the vertical section, U, divided by the terminal free settling velocity of the largest particle that reports to the overflow, u_t:

$$F = \frac{U}{u_t} \tag{1}$$

The well known PNK theory of Ponder [13], and Nakamura and Kuroda [14] has been used to estimate the increase in the hydraulic capacity of inclined channels over conventional thickeners and, in many cases, has been relatively accurate. For plug flow and with the assumption that any particle that settles onto the lower channel surface will slide back down into the fluidized chamber, the PNK theory predicts a theoretical throughput advantage of [4]:

$$F_{theory} = 1 + \left(\frac{L}{z}\right)\cos\theta\sin\theta \tag{2}$$

Here, θ is the angle of inclination relative to the horizontal, L is the channel length and z is the channel gap spacing perpendicular to the direction of fluid flow (see Fig. 1). Hence L/z is the aspect ratio of the channels.