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Water-only laboratory coal fractionation using the reflux classifier

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ABSTRACT

Due to health and environmental factors involved with standard float-sink analytical methods, a water-only fractionation procedure was investigated. A laboratory scale 105 × 105 mm reflux classifier was built and used to fractionate fine coal into a number of density classes. The procedure was tested against standard float and sink methods. The reflux classifier was found to be an effective fractionation method, especially if the fractioned samples were to be used in further chemical or reactivity investigations that could be affected by the dense medium adhering to the coal particle surfaces. The procedure was easier, safer and less tedious to perform in the laboratory. Higher density cuts could be achieved, and any number of density intervals could be prepared. It was also confirmed that the separation in the reflux classifier was not totally independent of particle size but it operated well for narrow size distributions above 355 μm. Tracer tests were also done, and it was shown that tracer partition results were a poor predictor of the reflux classifier performance because of hindered settling effects.

1. Introduction

In cases where minerals and ores, such as coal, are beneficiated on the basis of density, it is essential to determine the washability (or the density distribution) characteristics of the material to predict or assess plant performance. This involves separating the sample into density classes and determining the relative amounts in such classes. The material in these classes may be further analysed for other properties; in the case of coal, the densimetric- and ash curves are generated by float and sink analyses. Furthermore, it is often required in laboratory studies on reactivity, for example, to fractionate a coal sample into sub-samples of a narrow density range before use. This is done to isolate samples with certain required properties, like mineral content, maceral distribution or calorific value.

Galvin (2006) comprehensively described different washability determination methods that can be used. The options include float and sink analyses using organic liquids like white spirit, tetrabromoethane (TBE) or bromoform, or aqueous solutions of salts like zinc chloride, ($ZnCl_2$) suspensions. Apart from the obvious toxic and hazardous properties of the organic liquids, another concern was the adherence of the medium to the surface and in the pores after the fractionation procedure. This would influence any subsequent chemical analytical technique. The paper concluded that water-only systems would be worth pursuing.

Earlier work demonstrated the principle that particles of different size could be successfully separated by density using a high-density suspension at low fluidization rates. This was however still only applicable to a narrow particle size ranges (Moritomi et al., 1982). Galvin and Pratten (1999) used this principle to show that water only methods, like elutriation, showed reasonable agreement with traditional float-sink methods for narrow size ranges. The procedure was evaluated later (Callen et al., 2002) and it was found that a discrepancy between traditional float and sink methods and elutriation always existed in the lower density regimes. This was possibly due to particle mixing due to dispersion, and it was addressed by introducing a correction factor to the lower part of the yield-ash curve. Galvin et al. (2009) developed a relationship to predict the critical hydraulic velocity in lamella plate channels U' to yield the required sample density:

$$U' = k'(\Delta\rho z)^{2/3}\left(\frac{z}{\rho\mu}\right)^{1/3} \quad (1)$$

where k' is a constant, $\Delta\rho$ is the difference in densities between the fluid and the solids, ρ is the fluid density, z is the interplate spacing and μ the fluid viscosity. This relationship applies to flow in the intermediate flow regime, and demonstrated the particle size independency of the separation in a reflux classifier.

The reflux classifier was shown to be an innovative technology for density separation that combined a conventional fluidized bed

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and inclined parallel lamella plates. It achieved much higher throughputs and sharper separations (Nguyentranlam and Galvin, 2001; Galvin and Nguyentranlam, 2002; Nguyentranlam and Galvin, 2004). It also found wide application in industry, not only coal but also other commodities (Galvin et al., 2002, 2005; Zhou et al., 2006; Doroodchi et al., 2006). Modifications to the channel gap size ratios (Galvin et al., 2010) caused a reduction of the particle size effects and enabled the reflux classifier to process material of wider size ranges. The role of shear induced inertial lift (Galvin and Liu, 2011) was later described as the primary reason for these observations.

While separation by reflux classification was identified as an applicable method for washability analysis (Callen et al., 2002), this paper also focuses on the use of a laboratory scale reflux classifier to produce narrow density fractional samples to be used for further experiments, for example involving pyrolysis, gasification or combustion.

2. Experimental method and materials used

A 0.105 m cross-sectional diameter laboratory scale reflux classifier was designed and constructed using 10 mm PVC sheets (Fig. 1). It had 23 stainless steel plates in the lamella section spaced 3.5 mm apart at an angle of 70° from the horizontal. It was designed to operate in both batch and continuous operation, depending on the requirements of the project.

For this project the equipment was run in batch mode by introducing a feed sample into the fluidised section before operating the reflux classifier. Two series of tests were done: batch fractionation and batch separation. For batch fractionation, the classifier was operated at a fixed fluidizing water flow rate while collecting the overflow material until a clear overflow containing no solids was obtained. The flow rate was then increased to displace additional material to the overflow, forming another overflow sample with a higher density. The process was repeated until a final high-density sample was left in the fluidized section. All the overflow samples produced at each flow rate, plus the remaining underflow was collected, dewatered and dried, and analysed for mass, size, ash and density. In batch separation mode, the water flow rate was set at a single predetermined flow rate, and the material separated into two fractions: an overflow and underflow fraction.

The coal used in this study was an unwashed spiral feed from a colliery in the Waterberg coalfield in Limpopo Province, South Africa. It is known to be a highly laminated coal, alternating in bands of bright and dull coal as well as mineral matter which vary significantly in density (Jeffrey, 2005). The received sample was crushed, screened and de-slimed to between 1400 μm and 150 μm.

The density and particle size determinations were done using a Quantachrome SPY-4 helium stereo pycnometer and a Malvern Mastersizer 2000 laser diffraction particle size analyser respectively. Float-sink analysis was done according to the SANS 7936:2010 standard (South African National Standards, 2010) using zinc chloride as heavy medium. This standard is equivalent to the ISO 793:1992 standard. Ash analyses were done using the ISO 1171: 2010 standard.

Magnetic density tracers, supplied by Tenova Mining and Minerals South Africa (Pty) Ltd., of size 1 mm and densities ranging from 1.3 g/cm^3 to 2.0 g/cm^3 in 0.1 g/cm^3 increments were used in some of the tests. According to the tracer manufacturers, there was a tolerance of 10% in both the density and the particle size specifications.

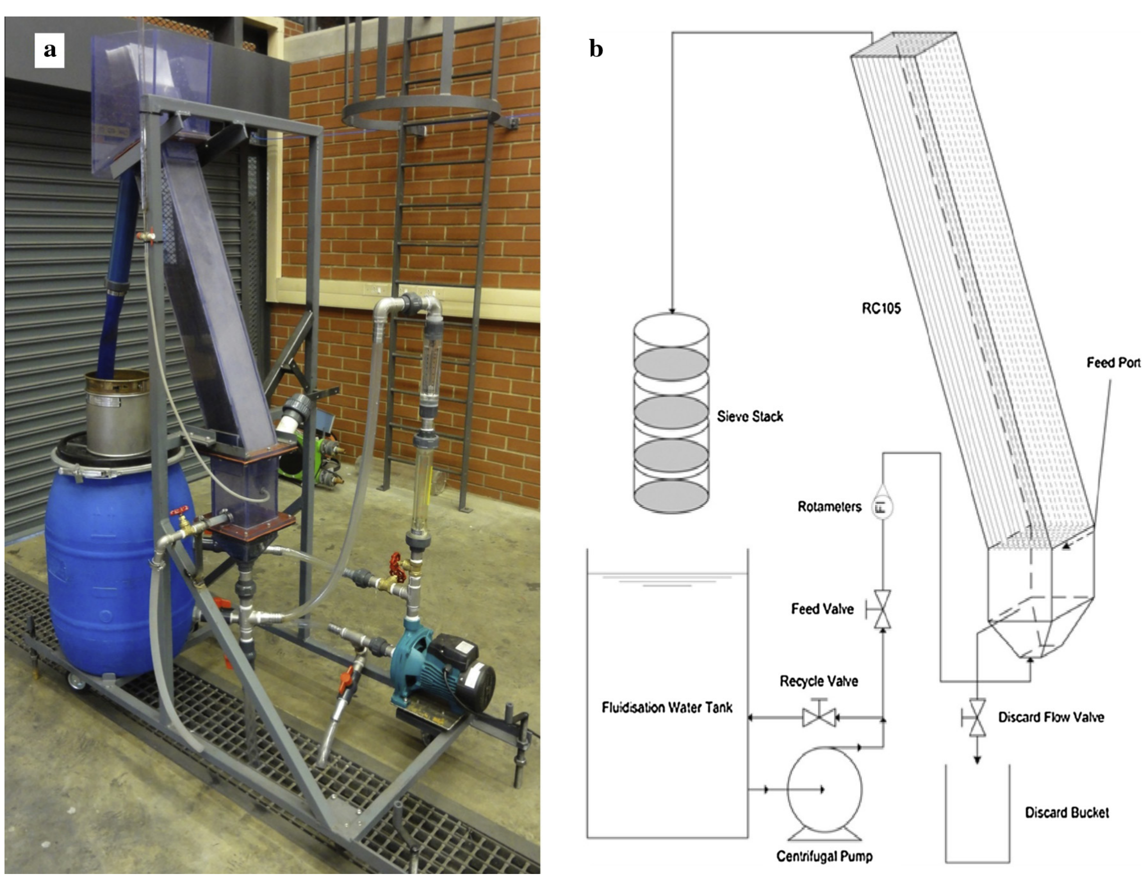

Fig. 1. Photograph (a) and schematic (b) of the experimental laboratory reflux classifier.