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The Potential for Dense Medium Separation of Mineral Fines Using a Laboratory Falcon Concentrator

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Abstract

Dense medium separation (DMS) is a technique used to separate particles based on specific gravity. Conventional DMS is, however, limited to coarse particle sizes and is not practical when processing fines. To improve the separation efficiency when processing fine particles, centrifugal separators have been employed. This work investigated DMS in a lab centrifuge and a modified Falcon Concentrator, in order to process the slimes of a rare earth ore. It has been shown that centrifugal concentration using a dense medium is possible when recovering values from a slimes fraction. Both the lab centrifuge and modified Falcon Concentrator resulted in a similar performance.

Keywords: Dense medium separation; Centrifugal separation; Falcon Concentrator; Fine particle separations

1 Introduction

Dense medium separation (DMS) is a process by which particles are separated based on differences in specific gravity (SG). The process can be controlled with a high degree of precision over a wide range of separating densities and is commonly applied as a pre-concentration step for minerals (such as cassiterite) and in the separation of coal from contaminants (Wills and Finch, 2016). An aqueous suspension of fine particles (significantly finer than the particles that are being separated) or a heavy liquid with a predetermined density is utilised as the medium and particles with a SG less than the liquid will float and those with a SG greater than the liquid will sink. Traditionally, DMS is performed using static bath separators, for which separation is only practical at coarse particle sizes (> 4 mm) as the slow settling rates of fine particles result in a poor separation efficiency (Wills and Finch, 2016). To improve the separation efficiency of finer particles, centrifugal separators have been employed to aid in their migration through the dense medium. Industrially, centrifugal DMS is considered practical for particle sizes down to 0.5 mm in diameter (Wills and Finch, 2016), however, several initiatives to beneficiate fine coal have shown that good separation can be achieved for particle sizes down to 25 μm (Aktaş *et al.*, 1998; Klima *et al.*, 1995), and more recently, work by Hirajima *et al.* (2005), investigating centrifugal DMS for the recycling of rare earth-activated phosphors from waste fluorescent lamps, demonstrated effective separation of particles with a size of 3 – 13 μm.

The use of a centrifuge to separate material on the basis of density is not only limited to DMS. A similar process to centrifugal DMS, known as density gradient centrifugation, is widely used in molecular biology for separating particles such as viruses, ribosomes or molecules (such as DNA) (Brakke, 1951; Work and Work, 1978). Centrifuges are also employed to separate suspended solids from liquids in other industries, such as food and agriculture, pharmaceutical and biotechnology, environmental industries, and chemical industries (Beveridge, 2000).

This work investigates using a modified laboratory scale Falcon Concentrator as a DMS centrifuge to process fines from the Nechalacho deposit in Canada, which is being investigated for its rare earth potential (Jordens *et al.*, 2013; Jordens *et al.*, 2014; Xia *et* *al.*, 2015). While there are multiple rare earth minerals in this deposit, zircon is the mineral of greatest importance due to its high content of the significantly more valuable rare earth elements (Ciuculescu *et al.*, 2013; Grammatikopoulos *et al.*, 2011).

2 Materials and Experimental Methodology

2.1 Materials

The raw material used in this work was obtained from the Nechalacho Deposit (Avalon Advanced Materials Inc., Canada) located in the Northwest Territories of Canada. Prior to DMS experiments, the ore was subject to a series of gravity and magnetic separation experiments detailed in Jordens *et al.* (2016). The gravity tailings were then passed through a lab-scale model WD(20) wet drum permanent magnet to remove magnetite. The non-magnetic fraction was then passed through a 2” de-sliming hydrocyclone (Salter Cyclones Ltd, UK) with a cut size of approximately 4 μm and operating pressure of 30 psi. The slimes fraction (overflow) of the hydrocyclone was then used as the feed (d_{50} = 3.9 μm, d_{80} = 11.2 μm) for the DMS experiments. Lithium metatungstate (LMT) [LMT Liquid, LLC (USA)] with a density of 2.95 was used for all DMS experiments.

2.2 Dense Medium Separation in Lab Centrifuge

Centrifugal DMS was performed using an IEC Centra CL2 centrifuge (Thermo Electron Corporation, USA). Samples were added to 35 mL of heavy liquid solution to give a solid content of 12.5 $\%_{w/w}$ in 50 mL centrifuge tubes. The suspensions were then mixed by hand shaking the sample and centrifuged for 15 min at 4400 rpm. Six repeat tests were performed and the heavy and light fractions from each were mass balanced and analyzed separately using x-ray fluorescence (XRF) analysis. All XRF analysis in this work was performed using a Niton XL3t GOLDD+ XRF analyzer (Thermo Fisher Scientific, USA).

2.3 Dense Medium Separation in a Modified Falcon Concentrator

The Falcon Concentrator (model SB-6A manufactured by Sepro Mineral Systems, Canada) used in this work was equipped with an ultrafine (U/F) bowl. The unit was modified with a lid to seal the bowl, allowing for the sample and heavy liquid to be contained throughout the experiment. The bottom of the bowl was filled with a mouldable plastic to create a flat base for ease of emptying. A schematic of the modified Falcon U/F bowl can be seen in Figure 1. Prior to beginning the test, the sample was added to 200 mL of heavy liquid solution to ensure a solid content of 12.5 $\%_{w/w}$. The Falcon Concentrator was operated at 1550 rpm for 60 min. Particles which remained attached to the bowl walls after operation were considered the "heavy" fraction and the remaining particles made up the "light" fraction. Four repeat tests were performed and light and heavy fractions from each test were then individually analyzed using XRF analysis.

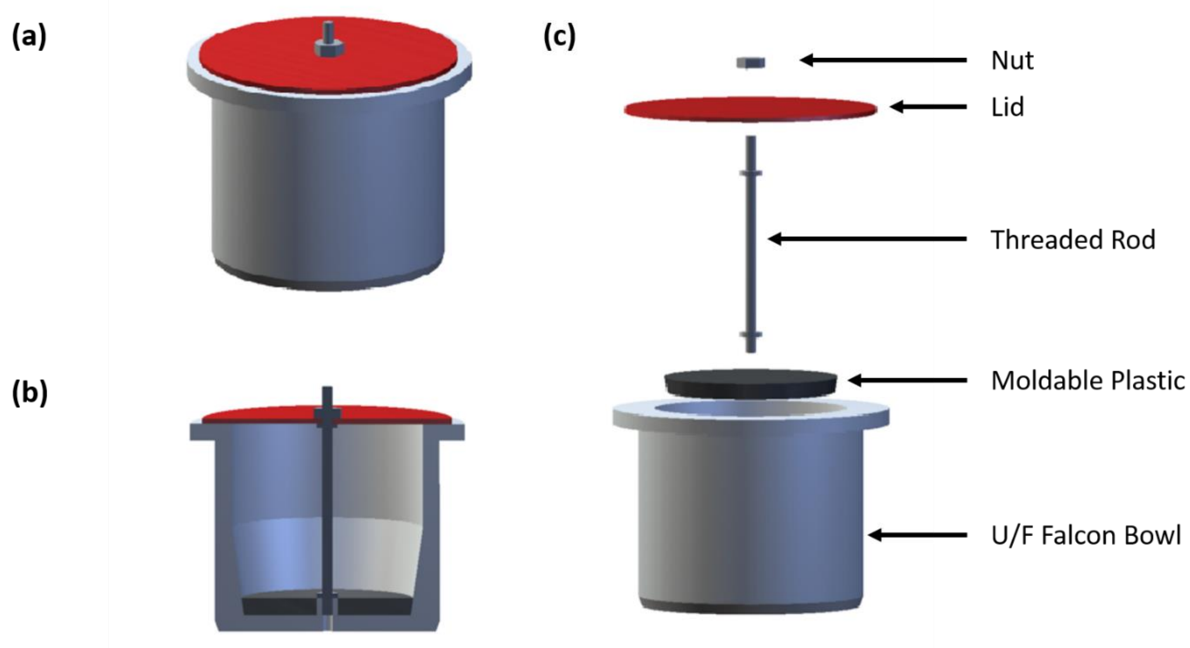

Figure 1 *(a) front view, (b) cross-sectional view and (c) exploded view of the modified Falcon U/F bowl*

3 Results and Discussion

3.1 Dense Medium Separation in Lab Centrifuge

The elemental grades and recovery of the heavy and light fractions produced from DMS performed in a lab centrifuge are shown in Table 1 and 2 respectively. The elemental distribution indicates that Zr, and therefore zircon (SG 4.65) (as it is the only Zr bearing mineral in the deposit), is more abundant in the heavy fraction, with an upgrade ratio of 2.9. The recovery of zircon to the heavy fraction is 71 %. The increased Fe content in the heavy fraction also suggests that iron oxide minerals [magnetite (SG 5.17) and hematite (SG 5.26)] are being concentrated. However, the relatively low recovery of Fe (46.9 %) in the heavy fraction may suggest that these minerals remain locked to silicate gangue, causing them to report to the light fraction. The elevated Si content in the light fraction, suggests that silicate gangue minerals [quartz (SG 2.65) and feldspars (SG 2.55-2.76)] are reporting to the light fraction.

Table 1 *Elemental grade of heavy and light fractions produced from DMS in a lab centrifuge*

Sample	Si (%)	95 % confidence	Fe (%)	95 % confidence	Zr (%)	95 % confidence	W (%)	95 % confidence
Feed	12.0	0.7	8.3	0.5	1.2	1.0×10^{-2}	1.4×10^{-2}	4.2×10^{-3}
Heavy	7.1	1.0	16.6	0.9	3.5	0.2	1.6	0.5
Light	14.8	1.6	5.5	1.0	0.4	0.1	0.5	0.1

Table 2 *Elemental recovery of heavy and light fractions produced from DMS in a lab centrifuge*

Sample	Si (%)	95 % confidence	Fe (%)	95 % confidence	Zr (%)	95 % confidence
Heavy	12.2	2.2	46.9	4.9	70.8	5.7
Light	87.8	2.2	53.1	4.9	29.2	5.7

While Table 1 suggests that heavy (SG > 2.95) minerals, most notably zircon, are being concentrated in the heavy fraction it is important to note that there are some discrepancies in the reported values when compared to the feed sample (average of 5 samples analyzed by XRF analysis). This is due to the LMT remaining in the samples after DMS (indicated by the elevated concentration in W in both the heavy and light fractions). This indicates that more work is required to ensure all entrained heavy liquid is removed from the samples, however, W content remains relatively low and is likely to have minimal effect on the values reported in this work.

3.2 Dense Medium Separation in a Modified Falcon Concentrator

The elemental grades and recoveries of the heavy and light fractions produced from DMS performed in a modified Falcon Concentrator are shown in Table 3 and 4 respectively. Similar to the results obtained for the lab centrifuge, the results suggest that heavy minerals (SG > 2.95) are being concentrated in the heavy fraction while minerals with relatively low densities (such as silicate gangue) are reporting to the light fraction. Using the modified Falcon Concentrator results in similar grades to those obtained when using the lab centrifuge, however, significant decreases in recovery are observed. The decreases in Zr and Fe recovery are likely due to the fact that the centrifugal acceleration in the modified Falcon Concentrator (130 times Earth's gravitational acceleration) is much lower than that in the lab centrifuge (2100 times Earth's gravitational acceleration). The significant reduction in centrifugal acceleration likely prevents ultrafine particles from migrating to the wall of the U/F bowl to be collected. This may be a limitation for DMS in a modified Falcon Concentrator, however, more work is required to optimize the process to determine if further improvements in recovery can be made.

Table 3 *Elemental grade of heavy and light fractions produced from DMS in a modified Falcon concentrator*

Sample	Si (%)	95 % confidence	Fe (%)	95 % confidence	Zr (%)	95 % confidence	W (%)	95 % confidence
Feed	12.0	0.7	8.3	0.5	1.2	1.0×10^{-2}	1.4×10^{-2}	4.2×10^{-3}
Heavy	9.5	0.8	16.0	1.0	4.0	0.3	0.4	0.1 0.07
Light	14.8	2.2	5.8	0.5	0.7	0.1	0.5	0.2

Table 4 *Elemental recovery of heavy and light fractions produced from DMS in a modified Falcon concentrator*

Sample	Si (%)	95 % confidence	Fe (%)	95 % confidence	Zr (%)	95 % confidence
Heavy	9.6	2.3	31.4	2.6	48.4	4.3
Light	90.5	2.3	68.6	2.6	51.6	4.3

4 Conclusions

It has been shown that centrifugal concentration using a dense medium is possible when recovering values from a slimes fraction. The use of a modified Falcon Concentrator U/F bowl resulted in a similar performance to that of the standard centrifuge used. Further work is required to optimise this process, and to remove all entrained heavy liquid.

This technique has potential for processing high value slimes, where any loss of value may have a significant impact on the profitability of a mineral processing plant.

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