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Effect of operational conditions on Falcon concentrator performance with different particle size fractions

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ABSTRACT

The present study investigates the effects of particle size distribution on Falcon concentrator efficiency with both narrow particle size fractions and a whole particle size distribution under different operational conditions. Eight narrow particle size fractions and a whole distribution composed of 10% of each particle size were tested with an L-40 Falcon concentrator at different washing water pressures and varying artificial gravity forces, generated by a centrifugal force, using samples composed of 2% magnetite (Fe₃O₄) and 98% calcite (CaCO₃) by weight.

The experimental conditions were tested and the performance of the Falcon concentrator was investigated and compared not only for each fraction but also for the whole particle size distribution together.

The total recovery for the narrow particle size fractions was calculated at 53.37%, which is 79.11% greater than whole distribution recovery for the same grade.

The results show that the performance of the concentrator increased with the narrow size fractions, and there are huge recovery differences between the optimum conditions for the whole distribution and narrow distributions. The operating conditions vary for each size. The Falcon concentrator thus has specific working conditions, and must be operated under optimum conditions for the different particle sizes to achieve better recoveries.

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Falcon concentrator; particle size; gravity separation; water pressure effect; centrifugal force effect

1. Introduction

Gravity concentration is the oldest separation method for minerals and operates by utilizing gravity and other forces, which are generally related to the resistance to motion offered by a viscous fluid (Burt 1984, 1999). Gravity concentration offers numerous advantages such as low capital and operating costs, and high efficiency. In addition, it does not require any chemicals or excessive heating requirements, and thus it can be considered environmental friendly (Turner 1991; Luttrell, Honaker, and Phillips 1995; Laplante and Spiller 2002; El-Midany and Ibrahim 2011).

Gravity separation produces clean concentrates, valuable fractions of minerals, and less valuable tailings. Generally, the separation efficiency decreases as the particle size of the processed mineral becomes finer (McAlister 1992; Parekh and Abdel-Khalekh 2002; Oruc, Ozgen, and Sabah 2010).

Gravity concentration has a lower efficiency for particle sizes of less than 100 μm. It is a very disadvantageous method for separation at these sizes without imparting an extra force on the particles. Thus, enhanced gravity separators have been developed (Traore et al. 1995; Honaker, Wang, and Ho 1996; Anca, Frenay, and Dandois 1997; Honaker 1998; Kökkılıç, Langlois, and Waters 2015). As a result, Falcon concentrators are increasingly used in the industry.

The separation principle of Falcon enhanced gravity concentrators depends on enhancing gravity with a centrifugal force to separate minerals according to their density differences. In particular, Falcon concentrators are increasingly used in gold mining, fine coal cleaning, and with other valuable minerals which have certain density differences. The Falcon concentrator includes a spinning bowl which is fed from its top; it drains the slurry along the wall of the bowl as a thin film through centrifugal force. The magnitude of the artificial gravity created by the centrifugal force depends on the rotation rate; it can be increased to as much as 300 times that of Earth's gravity (Falconer 2003). As a result, it is possible to separate particles based on their differential settling velocities, even in the ultrafine size range (Deveau and Young 2005; Deveau 2006). This action causes heavy particles to be transported to the inside canals of the bowl, whereas the light particles move to the outside with the water (Laplante and Shu 1993; Laplante et al. 1994; Abela 1997; Laplante and Nickoletopoulos 1997; McAlister and Armstrong 1998; Kroll-Rabotin and Sanders 2014; Marion et al. 2017).

All gravity concentration devices operate more efficiently with prepared feeds, i.e., with particles of a comparatively narrow size range (Burt 1984; Burt et al. 1995). Generally, separation processes have the advantage of large density

differences between minerals; however, in some cases, there are not large differences between the minerals to be separated. In these cases, a narrow particle size distribution should be considered to produce the greatest efficiency in the separation process.

2. Material and methods

In the present study, the performance of a Falcon concentrator was investigated with both wide and narrow size fractions in the presence of varying operational parameters. These operational parameters were the particle size, centrifugal force, and washing water pressure. Artificial samples, not only whole distribution but also each narrow size distribution consisting of 2% magnetite (Fe_3O_4) and 98% calcite (CaCO_3) by weight, were used in the tests to allow for easy analysis. An L-40 model Falcon concentrator was used for the tests.

Unliberated particle performance losses were eliminated in this study by using a completely liberated sample. Samples were tested at eight different particle size fractions starting from 600 μm and a whole particle size distribution under 600 μm with washing water pressures varying between 0.3 bar and 1.5 bar and centrifugal force levels of 20 G to 305 G. The centrifugal force is calculated from the frequency of bowl turns as indicated in the Falcon concentrator manual. The Falcon concentrator has between 0 to 0.25 tons per hour solid capacity, 2.3 m^3 per hour slurry capacity and it needs to process water between 0.24 and 1.2 m^3 per hour. The recommended maximum particle size is 1 mm and the recommended maximum water pressure is 3 bar. It generates a centrifugal force which can be increased between 20 and 300 times of gravitational acceleration effects depending upon bowl rotation rate. The bowl has 110 mm height, 30 mm diameter in the bottom and 95 mm in the top with 73.5° angles. The total concentration surface area is 0.03 m^2 . The solid content of the feed was fixed at 45% by weight, as determined by a series of pre-experiments. The general test conditions are summarized in Table 1.

The performance of the Falcon concentrator was investigated and compared not only for each fraction but also for the whole particle size distribution together.

All tests were conducted in batches. There were two designated discharge units in the system for collecting the concentrate and tailing. Thus, samples were fed into the separator directly, and the products were removed as concentrate and tailing. The recovered products were then dried and weighed. The magnetite in the concentrate was

separated with a magnetic separator and weighed to analyze the product and determine the recovery and grade of the process.

For each test, the equipment was cleaned, controlled, and then operated in a manner appropriate for the new test conditions. To make comparisons between the performances of the whole particle size distribution (under 600 μm) and the eight narrow size fractions, concentrates from all tests were treated in the same way.

3. Results and discussion

Although there are some other hydrodynamic forces that can affect the particle such as drag force, friction force, and water buoyant force, the particle escaping from or sticking to the concentrator wall depends on the main acting forces such as centrifugal force, gravity force, and water pressure force. If the water pressure force, is greater than the resultant force of centrifugal force and gravity force then the particle escapes from the concentrator wall otherwise it sticks on. Once the particles move from the wall, they get entrained by water on the outside of the bowl. Since the gravity force that is acting on the particle is constant, the resultant force depends on centrifugal force directly. Hence, the centrifugal force and washing water force have an inversely proportional relationship.

The test results also confirm that there is an inversely proportional relationship between the centrifugal force and washing water pressure. Thus, these two parameters were evaluated together as a new variable, G/P, where G is the artificial gravity force and P is the water pressure. The relationships between G/P and recovery, grade, and bulk recovery were investigated separately for each particle size fraction and the whole distribution. The Falcon concentrator did not perform under certain test conditions. With finer particle sizes, all of the material was washed away through the effect of the washing water, even at a centrifugal force of 276 G. Thus, the minimum washing water pressure of 0.3 bar was used for the fraction under 38 μm . In contrast, the Falcon concentrator became choked by the centrifugal force even at the maximum washing water pressure of 1.5 bar with coarser particle sizes. Because of these phenomena, the minimum washing water pressure and maximum centrifugal force are used for finer particle sizes, while the maximum water pressure and minimum centrifugal force are used for coarser particle sizes. This is the reason the G/P parameter was created to represent the relationship between the operational parameters of the Falcon concentrator. The relationships between G/P and the bulk recovery, recovery, and grade are logarithmic, linear, exponential for each fraction respectively. Figures 1–9 show the relationships between G/P and the bulk recovery, recovery, and grade.

In the –600 + 425 μm fraction, the concentrator was being choked up in 0.5–1 bar water pressures for all artificial gravity values, but in 1.5 bar water pressure, the concentrator was able to operate for artificial gravity values between 20 G and 99 G. This is shown in Figure 1.

Table 1. Test conditions.

Particle size (μm)	Water pressures (bar)	Centrifugal force (G)
–600 + 425	0.3–1.5	20–305
–425 + 300	0.3–1.5	20–305
–300 + 212	0.3–1.5	20–305
–212 + 106	0.3–1.5	20–305
–106 + 75	0.3–1.5	20–305
–75 + 38	0.3–1.5	20–305
–38	0.3–1.5	20–305
–600 + 0 (Whole distribution)	0.3–1.5	20–305

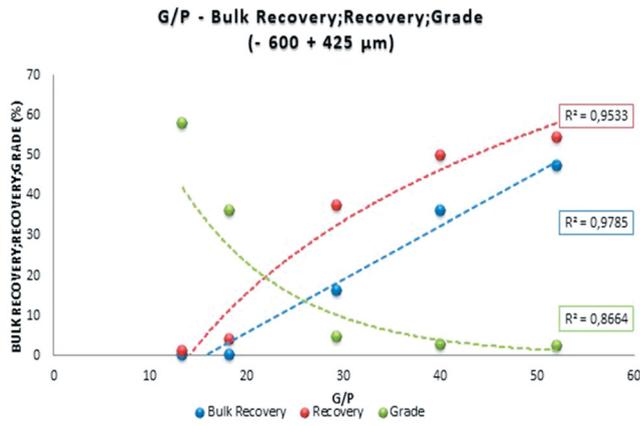


Figure 1. G/P vs bulk recovery, recovery and grade at the $-600 + 425 \mu\text{m}$ fraction.

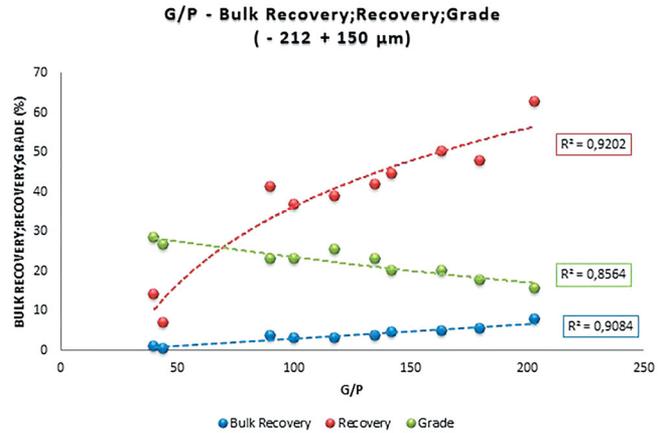


Figure 4. G/P vs bulk recovery, recovery and grade at the $-212 + 150 \mu\text{m}$ fraction.

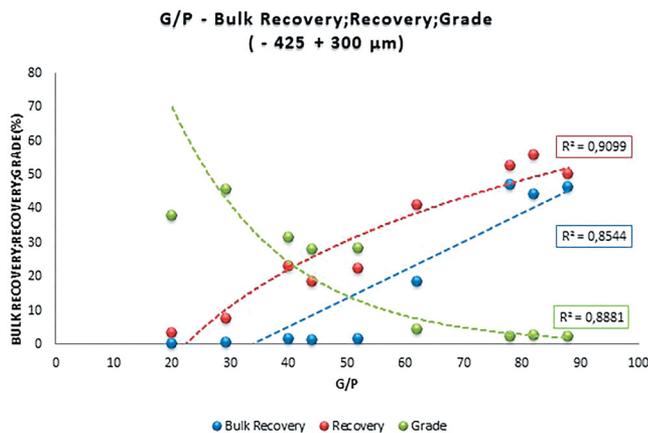


Figure 2. G/P vs bulk recovery, recovery and grade at the $-425 + 300 \mu\text{m}$ fraction.

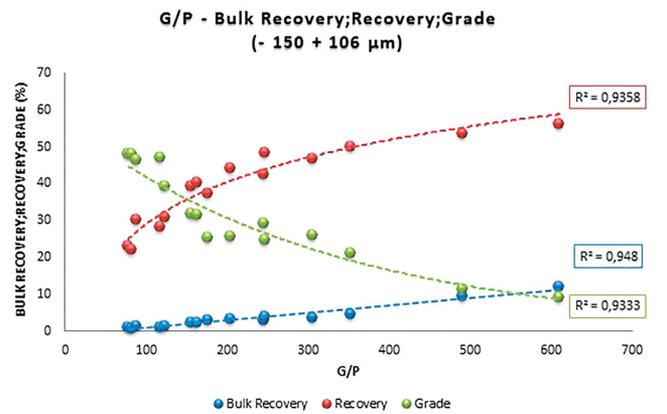


Figure 5. G/P vs bulk recovery, recovery and grade at the $-150 + 106 \mu\text{m}$ fraction.

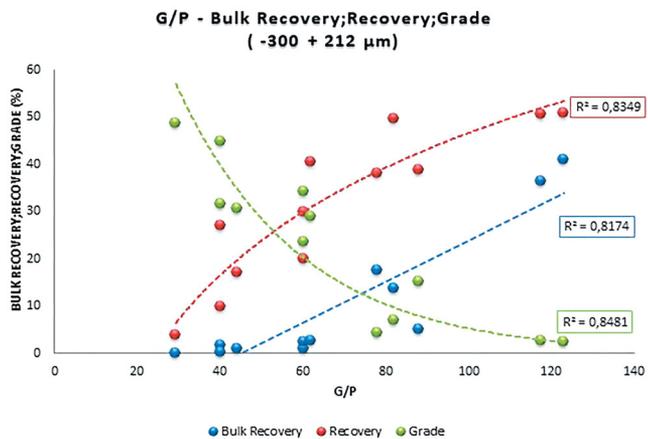


Figure 3. G/P vs bulk recovery, recovery and grade at the $-300 + 212 \mu\text{m}$ fraction.

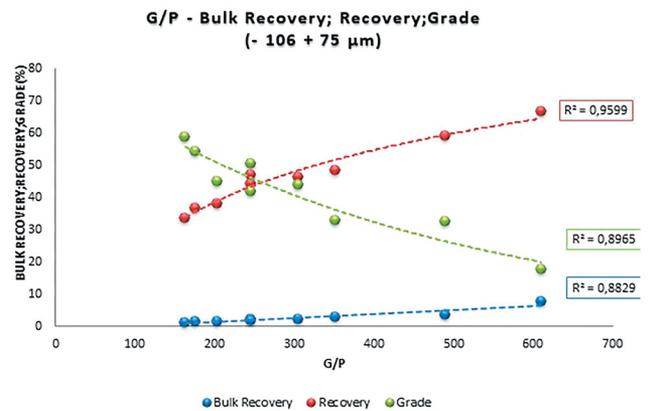


Figure 6. G/P vs bulk recovery, recovery and grade at the $-106 + 75 \mu\text{m}$ fraction.

In the $-425 + 300 \mu\text{m}$ fraction, the concentrator was being choked up in artificial gravity values between 78 G and 305 G for 0.5 bar water pressure, between 99 G and 305 G for 1 bar and between 123 G and 305 G for 1.5 bar water pressure. Moreover, the 1.5 bar water pressure caused washing out of all material from the concentrator in 20 G gravity values. The other tests conditions were operated and the results are shown in Figure 2.

In the $-300 + 212 \mu\text{m}$ fraction, the concentrator was being choked up in artificial gravity values between 78 G and 305 G for 0.5 bar water pressure, between 99 G and 305 G for 1 bar and between 245 G and 305 G for 1.5 bar water pressure. Moreover, the 1.5 bar water pressure caused washing out of all material from the concentrator in 20 G. The other tests conditions were operated and the results are shown in Figure 3.

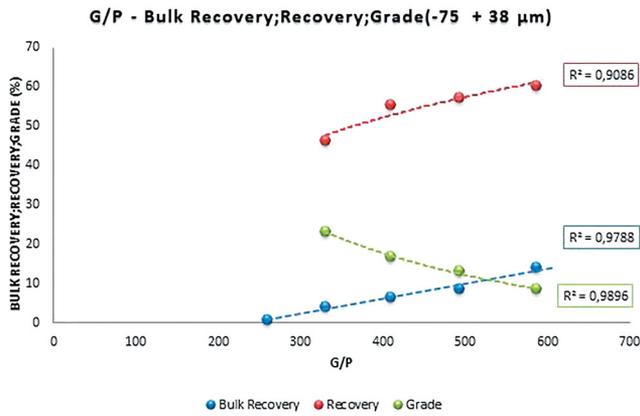


Figure 7. G/P vs bulk recovery, recovery and grade at the $-75 + 38 \mu\text{m}$ fraction.

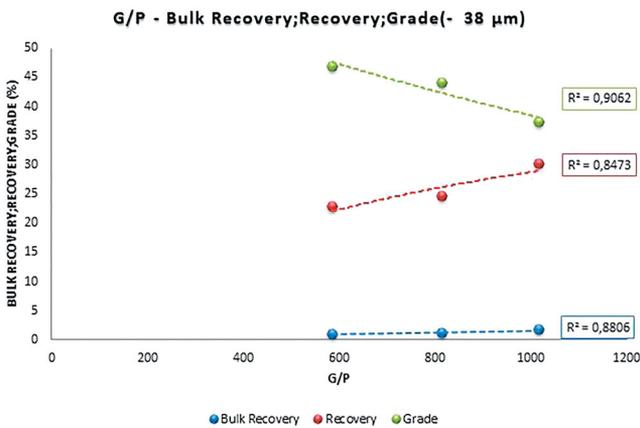


Figure 8. G/P vs bulk recovery, recovery and grade at the $-38 \mu\text{m}$ fraction.

In the $-212 + 150 \mu\text{m}$ fraction, the concentrator was being choked up in artificial gravity values between 176 G and 305 G for 0.5 bar water pressure, between 276 G and 305 G for 1 bar water pressure. Moreover, the 1.5 bar water pressure caused washing out of all material from the concentrator in between 20 G and 123 G. The other tests conditions were operated and the results are shown in Figure 4.

In the $-150 + 106 \mu\text{m}$ fraction, the 1 bar water pressure was caused washed all materials out from the concentrator in between 20 G and 44 G gravity values and 1.5 bar water pressure was caused for between 20 G and 78 G. The other tests conditions were operated and the results are shown in Figure 5.

In the $-106 + 75 \mu\text{m}$ fraction, the 0.5 bar water pressure caused washing out of all materials from the concentrator in between 20 G and 78 G gravity values, 1 bar water pressure was caused for between 20 G and 123 G and 1.5 bar water pressure was caused for between 20 G and 176 G. The other tests conditions were operated and the results are shown in Figure 6.

In the $-75 + 38 \mu\text{m}$ fraction, the 0.5 bar water pressure caused washing out of all materials from the concentrator in between 20 G and 44 G gravity values, 1 bar water pressure was caused for between 20 G and 123 G and 1.5 bar water pressure was caused for between 20 G and 245 G. The other tests conditions were operated and the results are shown in Figure 7.

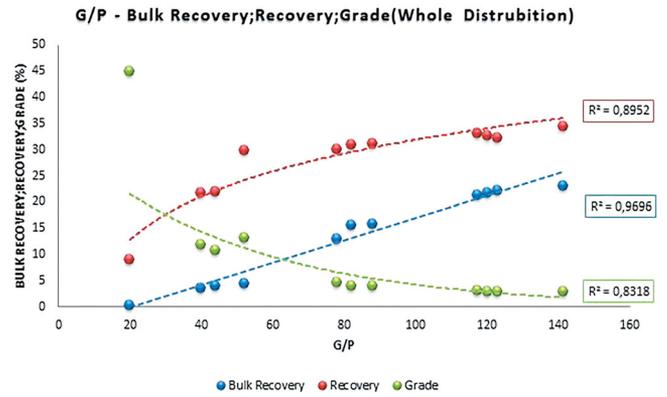


Figure 9. G/P vs bulk recovery, recovery and grade at whole distribution.

In the $-38 \mu\text{m}$ fraction, the 0.3 bar water pressure caused washing out of all materials from the concentrator in between 20 G and 123 G gravity values, 0.5 bar water pressure was caused for between 20 G and 245 G and 1 bar water pressure was caused for between 20 G and 245 G. The other tests conditions were operated and the results are shown in Figure 8.

In the $-600 \mu\text{m}$ (Whole) fraction, the concentrator was being choked up in artificial gravity values between 78 G and 305 G for 0.5 bar water pressure, between 176 G and 305 G for 1 bar and between 245 G and 305 G for 1.5 bar water pressure. Moreover, the 1.5 bar water pressure caused washing out of all materials from the concentrator between 20 G and 44 G. The other tests conditions were operated and the results are shown in Figure 9.

In fine sizes, all samples in the concentrator were washed out with the effect of washing water pressure whereas, the concentrator was being choked up in the coarse sizes. So, there was no chance to use the same artificial gravity values and washing water pressures for different particle size distributions. The evaluation of test results indicates that there is an inversely proportional relationship between artificial gravity force and washing water pressure. The falcon concentrator has specific working conditions and it needs to operate in optimum conditions for different particle size distributions to reach better performances.

Thus the G/P parameter was created for indicating a relationship between the operational parameters of the Falcon concentrator. The relationships between G/P and bulk recovery, recovery, and grade are logarithmic, linear, and exponential respectively. Figures 1–9 show the relationship between G/P and bulk recovery, recovery, grade.

4. Conclusion

The results of this study show that a grade of 26.40% was obtained with a 33.27% recovery in classified sample tests overall, whereas a grade of 13.23% was obtained with 29.8% recovery in the whole distribution sample. The highest grade for the whole distribution sample was 13.23%. Thus, the recovery values for each particle size fraction were read from recovery–grade graphs for each test condition using a grade of 13.23% for calculation of the total recovery and

Table 2. Read recovery values in different particle sizes.

Particle size (µm)	Recovery (%)*
–600 + 425	37
–425 + 300	38
–300 + 212	42
–212 + 150	69
–150 + 106	55
–106 + 75	72
–75 + 38	57
–38	57

*Read values from recovery-grade graphs in 13.23% grade.

comparison with grade-recovery values for the whole distribution sample. The resulting recovery values for each size fraction are listed in Table 2.

Under these conditions, the total average recovery of the narrow particle size fractions was calculated as 53.37%, which is 79.11% greater than the whole distribution recovery value for the same grade.

The results show that the operational conditions for the Falcon concentrator vary with each particle size. The performance of the concentrator increased with narrow size fractions, and there are huge recovery differences between the optimum conditions for the whole particle distribution and narrow particle distributions. Therefore, the Falcon concentrator has specific working conditions, and it must be operated under the optimum conditions for different particle size distributions to achieve better recoveries.

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