Recovery of fine gold particles using a Falcon ‘B’ separator

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ABSTRACT

Many gold treatment plants have sulphides and coarse particle gangue components that contain gold in their tailings (cyanide leach residues and flotation tailings). Coarse and very fine liberated gold may also be present in some tailings streams. Two issues usually govern the economics of recovering additional gold from gold occluded in sulphide and gangue particles. The liberation characteristics of the gold in the sulphide and coarse gangue (gold liberation versus grind size) is the first and most important of the two. If fine grinding can liberate a reasonable amount of the gold, then the next important issue is how effectively these two constituents can be concentrated.

Flotation will achieve high sulphide recovery but is usually costly. Selectivity is also an issue because of entrainment. Continuous centrifugal gravity concentration offers a viable solution to the recovery of both sulphides and coarse gangue however selectivity is also likely to be a problem.

The possibility of improving concentrate grade by using a Falcon B separator was investigated. This paper describes a program of test work carried out on a gold leach tailings using a laboratory Falcon ‘B’ separator. The program involved three different bowl angles: 10, 12 and 14 degrees and two bowl speeds (giving 250 and 350G accelerations). A number of tests were also performed on samples that had free gold present to ascertain the size-by-size recovery of gold in these samples.
INTRODUCTION

The introduction of modern centrifugal separators into the minerals industry has significantly decreased the size of particles recoverable using gravity concentration. One type of centrifugal concentrator used in the gold industry is the Falcon SB, a spinning bowl concentrator which operates under semi-batch conditions. By changing the bowl’s rotational speed via a variable speed drive a force of over 300G on the feed particles can be achieved (1), significantly higher than separators such as the Kelsey jig and the standard Knelson concentrator (which requires pulley changes to change the speed), both of which normally generate up to 60G (2). This increased separation force enhances the terminal velocity of particles which improves the separation of heavy and light particles especially in the finer size fractions (3).

The Falcon B is the simplest of the Falcon centrifugal concentrators and is suitable for fine feed applications requiring low mass recoveries. Unlike the Falcon SB, the bowl uses no fluidising water, concentrates are simply retained against the wall of the bowl. The Falcon B may offer metallurgical benefits such as improved recovery of fines and possibly concentrate grade in the fine particle size ranges. In cases where scavenging very fine gold-bearing particles is more important than the grade of concentrate produced, the Falcon B may be of considerable metallurgical value if the optimum operating conditions can be determined.

The work described in this paper was designed to optimise the operation of a four-inch diameter (laboratory scale) Falcon B concentrator to ascertain the metallurgical performance and determine the parameters for improving fine particle recovery especially that of gold. Three variables were investigated: bowl angle, bowl speed and solids feed mass.

Most of the test work was conducted on gold leach tailings (P₈₀ particle size is 36 microns) with a gold content of 0.55g/t and a sulphur (pyrite) content of 1.23%. Over 80% of the gold in the tailings is locked in silicates, mostly as very fine particles disseminated through the silicates. Only minor amount of gold is associated with sulphides or is possibly present as fine free gold.

As most of the very fine gold is occluded in the silicates, the density of the resulting composite particles is likely to be only a little greater than that of the silicates alone. Hence the analysis of the test work data involved examination of both gold bound in silicate and sulphur recoveries. It was felt that the recovery of fine sulphides (pyrite with a relative density of 4.5 which contain very little gold) might give an indication of the likely recovery of denser particles using the Falcon B separator.
The size distribution of the leach tailings, and the gold and sulphur distribution by size are given in Table I. The coarse fraction has a disproportionate amount of gold present (i.e. high grade compared to other size fractions), while the minus 21 micron fractions contain the majority of the sulphur.

Once the operating conditions for the best silicate bounded gold recovery had been found, an additional three tests were conducted on larger samples. This was followed by tests on a sample with a similar particle size distribution but with free gold present and a sample with a much coarser particle size distribution ($P_{80}$ of 84 microns).

Table I – Typical Size, Gold and Sulphur Distribution of Tailings Sample

<table>
<thead>
<tr>
<th>Size (µm)</th>
<th>Mass %</th>
<th>Gold Dist %</th>
<th>Sulphur Dist %</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>11.0</td>
<td>23.4</td>
<td>4.8</td>
</tr>
<tr>
<td>45</td>
<td>4.5</td>
<td>6.4</td>
<td>2.4</td>
</tr>
<tr>
<td>38</td>
<td>4.6</td>
<td>5.2</td>
<td>3.4</td>
</tr>
<tr>
<td>29*</td>
<td>1.3</td>
<td>8.5</td>
<td>12.6</td>
</tr>
<tr>
<td>21*</td>
<td>12.1</td>
<td>10.9</td>
<td>19.6</td>
</tr>
<tr>
<td>15*</td>
<td>13.6</td>
<td>5.1</td>
<td>19.9</td>
</tr>
<tr>
<td>11*</td>
<td>10.0</td>
<td>3.4</td>
<td>14.0</td>
</tr>
<tr>
<td>-11*</td>
<td>42.9</td>
<td>37.2</td>
<td>23.2</td>
</tr>
</tbody>
</table>

* Cyclosizer separation sizes based on a typical tailings SG of 2.65

TESTWORK

A feed mass of 1 kg per test was chosen to ensure that overloading of the concentrate bed did not occur. Test work on tantalum flotation concentrate reported in the literature by Deveau (4) suggested that a pulp density of 10 per cent or lower combined with high bowl speeds would give the highest recovery of very fine (minus 10 micron) particles. This pulp density was used throughout the test work.

Typical Falcon operating bowl speeds are designed to produce forces in the range of 200 to 300Gs. One speed within this range (250G) and one slightly higher (350G) were used. Bowls with three different wall angles: 10, 14 and 18 degrees were made available for the test work by Falcon Inc.

A solids feed rate of 50 kg/hr was used, similar to that adopted in previous test work by McAleese (5). The feed time for each test was calculated based on the feed mass, feed rate and pulp per cent solids.
Combinations of these variables gave a total of 6 tests in total to be conducted on the tailings material. The conditions used are summarised in Table II. Test 1 was repeated three times in order to estimate the experimental error associated with the test procedure.

Test work was conducted using the Falcon test rig at the Julius Kruttschnitt Mineral Research Centre (JKMRC). The 4-inch Falcon B separator was fed from a well-stirred sump using a peristaltic pump. The feed rate was accurately controlled by a variable speed drive fitted to the pump. Bowl speed was also accurately controlled by means of a second variable speed drive.

Table II – Test Work Conditions

<table>
<thead>
<tr>
<th>Test</th>
<th>Bowl angle</th>
<th>Bowl speed (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>350</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>350</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>18</td>
<td>350</td>
</tr>
</tbody>
</table>

At the end of each test, the spinning bowl was stopped and the concentrate washed into a steel collecting tray at the base of the bowl. The tails launder was washed clean with a water spray and all particles collected in a 20-litre tails sample bucket. The tailings and concentrate were filtered, dried and weighed and the mass recovery determined.

The entire concentrate filter cake was broken up and wet screened at 150, 53, 45 and 38 microns with the remainder sized at 20 microns using a cloth screen. A representative sample of approximately 200g of the tails was sampled and sized using the same method. Each fraction obtained through sizing was assayed for gold and sulphur.

Reserve samples of minus 38 micron material for both concentrate and tailings for all tests were retained. This was done so that once the parameter combination which provided the highest gold recovery was known, resizing of the minus 38 micron material from the optimum test could be performed. The material was resized at 11 microns using a cloth sieve to more accurately define fine gold recovery in the minus 20 micron range.
RESULTS

Concentrate mass recovery

The manufacturer of the Falcon suggests that bowl angle (measured as shown in Figure 1) plays an important role in determining the mass recovery to the concentrate (6). The angle alters the surface area and volume available for particles in the concentrate bed. For a 4-inch bowl, a maximum possible angle of 25 degrees from the vertical can be created. The vertical lines drawn inside the bowl in Figure 1 represent a particular thickness of the concentrate bed. It can be seen that as the bowl angle increases the volume of concentrate will decrease. As the majority of material is retained in the upper (vertical-sided) section of the bowl, small changes in bowl angle when using angles greater than about 20 degrees would not be expected to greatly affect the concentrate mass produced.

Figure 1 – Definition Of Bowl Angle

Figure 2 shows the mean concentrate mass recovery (mass-pull) from 1 kg of feed as a function of bowl angle from all the tests. The error bars indicate that there is some small variation in the mass of concentrate produced with each bowl angle but the trend expected from simple geometric considerations is clearly evident.

Gold and sulphur recovery

Figure 3 shows the overall recovery of gold for the six tests. The error bars are based on the results of the triplicate reproducibility tests. Test 3, with the 14 degree bowl, appears to give the best result, although surprisingly this test was not conducted at the highest G
force. The corresponding result for sulphur is shown in Figure 4, where interestingly the optimum sulphide recovery is achieved with the 10 degree bowl at 350G (Test 1). The error bars suggest that there may be little difference in performance due to the change in bowl speed.

![Figure 2 – Average Concentrate Mass Pull For All Tests](image)

![Figure 3 – Overall Gold Recovery For All Tests (Showing Test Numbers)](image)

The extent to which concentration is occurring may be gauged by comparing the size-by-size recovery of solids with the size-by-size recoveries for gold and sulphur for Test 3, which gave the optimum overall gold recovery. The solids recovery by size is shown in Figure 5, and across all size fractions is broadly similar.
The size-by-size recovery for gold is shown in Figure 6. The increase in gold recovery for minus 20 micron particles is clearly evident, indicating that in this size fraction the Falcon B is concentrating particles on the basis of density. When compared with the results for Test 4 at 350G (not shown), the error bars, based on the triplication of Test 1, also suggest that increasing bowl speed from 250G to 350G has no significant effect on recovery.

A similar result was observed for sulphur recovery, Figure 7. As the particle size decreases it can be seen that the Falcon B is concentrating the finer sulphide particles.

![Figure 4](image1.png)  
**Figure 4 – Overall Sulphur Recovery For All Tests (Showing Test Numbers)**

![Figure 5](image2.png)  
**Figure 5 – Size-by-Size Recovery Of Solids**
For comparison, Figure 8 shows the size-by-size sulphur recovery for Test 1, which resulted in the best overall sulphur recovery. Overall recovery increased to 34% compared with 22% for Test 3.

![Figure 6 – Size-by-Size Recovery Of Gold, Test 3](image)

To define the performance of the Falcon B in the minus 20 micron fraction more accurately, further analysis was performed. The reserve samples of minus 20 micron material from Test 3 (the optimum test) were screened using an 11 micron cloth screen and the undersize and oversize fractions assayed for gold. The extended size-by-size recovery of solids and gold are compared in Figure 9. It is clear that concentration of minus 20 micron
gold bearing particles is being achieved down to at least 11 microns. Recovery of both solids and gold appears to be declining somewhat in the minus 11 micron fraction. Possibly, due to the rapid flow of pulp, these ultra fine particles are being carried over the top of the spinning bowl with the water.

Figure 8 – Size-by-Size Recovery Of Sulphur, Test1

Figure 9 – Extended Size-by-Size Recovery Of Solids And Gold, Test 3

Grade and Recovery Relationship

Although gold recovery is important, the grade of the concentrate produced must also be considered. The average grade and recovery values for each bowl are plotted in Figure 10
for the minus 20 micron fraction. As the volume of the concentrate bed changes with varying bowl angle (Figure 1), it was expected that the bowl with the steepest bowl angle (10 degrees) would give the highest gold recovery at the lowest grade. Conversely, it was expected that the 18 degree bowl would produce the highest grade concentrate at the lowest recovery. The 10 degree bowl did indeed produce the lowest gold grade concentrates but not the highest recovery. However, highest sulphur recovery was achieved with the 10 degree bowl suggesting that despite the result for gold this bowl is most suitable for recovery of denser particles. As indicated earlier, most of the gold in the feed material tested is very fine and occluded in silicate particles, the resulting composites being only slightly denser than pure silicates. This fact may account for the lower than expected gold recovery with the 10 degree bowl.

The grades obtained with the 18 and 14 degree bowls are essentially the same, but the 14 degree bowl gave the best recovery.

![Gold Grade-Recovery Relationships For Different Bowl Angles](image)

Figure 10 – Gold Grade-Recovery Relationships For Different Bowl Angles

**Larger Feed Mass Tests**

Three additional tests were conducted with a feed mass of 5 kg, pulp density was maintained at 10% as before. The tests were conducted on feed samples with free gold (fine and coarse) using the optimum conditions for gold recovery established previously (250G, 14 degree bowl). These tests with leach feed samples establish the extent to which coarser free gold is recovered. The third test used the same fine leach tailings materials as in the earlier optimising tests.
Concentrate mass pull for the tailings samples was about 80g, similar to that with 1kg of feed, suggesting that this is the limit for this bowl size and angle. With the coarser sample feed mass pull increased slightly to 96g. Solids recovery on a size-by-size basis is shown in Figure 11. Results are similar to the 1kg feed mass tests, with a similar approximately constant solids recovery across the size range, but at lower values due to the mass pull remaining constant irrespective of feed mass.

![Solids Recovery From A 5kg Feed Mass](image)

The gold recovery by size results are shown in Figure 12 and demonstrate that the coarse free gold particles in the coarse feed are readily recovered. For the fine feed sample the gold recovery decreases with increasing particle size. As this stream is a cyclone overflow, it is likely that coarser particles contain only very small amounts of gold and their density is very little different from the gangue. Recovery of minus 20 micron gold-bearing particles was essentially the same for fine feed and tailings samples.

The tests with a 5kg feed mass demonstrated that gold recovery from the fine tailings was 10% lower in each size fraction compared with the 1kg feed mass test results shown in Figure 6. Sulphur recovery was substantially reduced, to approximately 5% in all size fractions irrespective of feed type (coarse or fine leach feed, fine leach tailings). This was attributed to overloading of the bowl with sulphides when the 5kg feed mass was used.
CONCLUSIONS

The objective of the work described in this paper was to investigate the effects of bowl angle, bowl speed (G force) and feed rate on the recovery of very fine gold in leach tailings using a Falcon B separator.

Best recovery of minus 20 micron gold was achieved with the 14 degree bowl. Replicate tests suggest that bowl speeds giving greater than 250G do not offer additional gold or sulphide recovery for these feed materials. Extending the size analysis to minus 11 microns demonstrated that the Falcon B is concentrating gold bearing silicate particles down to 11 microns. However, particles finer than 11 microns are beginning to follow the water flow into the tailings.

The optimum recovery of sulphur was achieved at different conditions. Best results were achieved with the 10 degree bowl. As the density of the fine gold bearing particles is likely to be only just greater than gangue density, due to the small amounts of gold present, the optimum conditions for denser sulphide mineral recovery are important indicator of the ability of the Falcon B to recover very fine dense particles.

Mass recovery to the concentrate was found to be a function of bowl angle, with the greatest mass recovery occurring with the smallest bowl angle, as expected from a simple geometric argument. Mass pull was similar irrespective of amount of feed.

Figure 12 – Size by Size Recovery Of Gold From The Larger Feed Mass Tests
When the feed mass was increased to 5 kg sulphur recovery dropped significantly due to bowl overloading, gold recovery dropped about 10% compared with the lower feed mass tests.

Substantial recovery of gold in all size fractions was possible from the much coarser feed, due to the higher proportion of free gold particles. Coarser particles in the fine leach feed may contain less gold, and the recovery of these particles is consequently lower.

REFERENCES


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