Gravity Recovery of gold — An overview of recent developments

A.R. Laplante  
*McGill University*  
*Department of Mining, Metals and Materials Engineering*  
*3610, University Street, Wong Building*  
*Montréal, Québec, Canada H3A 2B2*

W.P Staunton  
*AJ Parker Cooperative Research Centre for Hydrometallurgy*  
*Mineral Science, Division of Science & Engineering*  
*Murdoch University*  
*Murdoch WA 6150*  
*Australia*

**ABSTRACT**

Gold recovery early in the flowsheet, typically from the primary grinding circuit, has seen significant advances in the past three years. Some of the advances achieved under the auspices of the AMIRA P420B Gold Processing Technology project are reviewed. The areas covered are gravity-recoverable gold (GRG) characterization, GRG behaviour in classification, gravity recovery simulation and the link between gravity recovery and cyanidation.
INTRODUCTION

The AMIRA P420B Gold Processing Technology Project, an industry funded collaborative research project, which spanned the May 2001 – May 2004 period, had four major research areas, process optimization, thiosulfate development, cyanide and the environment, and complex and refractory ores. The first of these, plant optimization, explored the use of modeling to optimize gravity and CIL/CIP circuits. Ultimately, it is intended to link the gravity and CIL models, as the effectiveness of the gravity circuit determines the size distribution of the gold reporting to the feed of the leach circuit. Of particular interest is the gravity recoverable fraction that is not recovered by gravity, either in the absence of gravity recovery or due to limitations of the classification and gravity circuit, and subsequently report to the leaching. It will be demonstrated that for one site surveyed this fraction constitutes the slowest leaching component of the ore.

Figure 1 – Concept Map of the Gravity Research

Figure 1 presents the concept map of the gravity research program. The three poles of research are the characterization of gravity recoverable gold (GRG) in ores, determination of its behavior in comminution and classification units, and, finally, in recovery units. The three components are used to populate a phenomenological model of GRG behavior in grinding circuits, which can be used for design and optimization of recovery circuits, and also yields the size distribution of gold produced by grinding circuits and typically directed to cyanidation or flotation circuits. The gravity program in the P420B project consisted of four research axes: gold ores characterization, gravity circuit audits, the development of a web-based gravity recovery simulator, and studies linking gravity recovery and leaching kinetics. The most salient results are reported here.
GOLD ORE CHARACTERIZATION

The McGill protocol to characterize gravity recoverable gold (GRG) has been presented in Laplante et al. (1). It consists of a progressive (3 stage) liberation and recovery of gold-bearing particles using a laboratory centrifuge unit, which preserves the natural size distribution of gold. The first stage is performed at a $P_{80}$ of $550\pm50$ µm, the second at a $P_{80}$ of $160\pm20$ µm, and the third at a targeted $P_{80}$ of $75$ µm. Feed masses are high to achieve good sampling representativity and to minimize weight recovery, thus achieving high selectivity. The research program also probed the nature of GRG, developed a simpler GRG test that could be used more routinely, and explored the nature of marginal GRG.

MLA studies of GRG

The concentrates of four GRG samples were subjected to analysis using the Julius Kruttschnitt Mineral Research Centre (JKMRC) mineral liberation analyzer (MLA). The objective was to assess to what extent gold in GRG is liberated and can be recovered by gravity. A more detailed summary of this work has been presented in Guerney et al. (2).
Figure 2 shows the degree of liberation in three size fractions of the stage-1 concentrate of a sample from the Bulyanhulu mine, Tanzania. Liberation increases significantly with decreasing particle size, but is high enough for gravity recovery even in the coarsest particle size. The implication is that the coarser GRG particles may require regrinding to produce a high-grade concentrate. This was confirmed with the introduction of a small mill in the gold room, which had significant positive impact on gravity recovery. It has also been found that the coarser, less liberated GRG was more effectively captured using Knelson Concentrators (Model CD30) at a relatively low rotating velocity corresponding to a theoretical 55 Gs.

For three of the samples tested, liberation based on surface examination tended to underestimate recovery, since fragments of gangue material were typically at the surface of gold matrices. This is illustrated in Figure 3.

The MLA studies confirmed that the GRG test was selective enough to produce a reliable estimate of gold content that could be recovered at full scale into concentrates of very high gold grade. Its use extends far beyond, as it yields significant statistical data about associations of gold and other minerals.

Developing a Simpler GRG Test

The cost, labour and weight requirements (60-100 kg) of the regular GRG test preclude its use at mill site or for routine testing. A simpler alternative was deemed desirable; two alternative approaches were tested. A first option consisted of performing only stages 1 and 3, starting with 20 kg of material. A second option consisted of going directly to stage 3 with the same feed mass. These were dubbed the two-stage and the one-stage tests, respectively. In both cases, the final screen used was 25 µm rather than the 20 µm of the standard test.
Figure 4 – Comparison of the Standard GRG Test Results and the 2-Stage and 1-Stage Simplified Tests

Figure 4 compares the results of both tests to those of the standard test. Generally, the one-stage test slightly underestimates GRG content, whereas the two-stage test overestimates it. The data of Figure 4 actually slightly exaggerate differences between the standard and simplified tests, as other factors contributed to variations in the results. For example, the samples used for the QUE3, QUE4 and QUE5 simple tests were extracted differently and returned very different grades from the standard test samples. Despite these differences, tests results were very similar. Where the gangue is particularly abrasive (e.g. sample GHA), the quantity of GRG can be significantly underestimated, particularly with the one-stage test. Figure 5 shows that the size distribution of the lower GRG content of the simplified tests is then also finer. This phase of the work is nearing completion, and it is already clear that the one-stage test will be the preferred route over the two-stage test.

Table I lists the advantages and disadvantages of the one-stage test when compared to the standard test. Different roles for the standard test and simplified test emerge. For greenfield application or when a single sample is available, the standard test is clearly desirable, because of the extra accuracy and information provided. For routine or scoping test work, or when flotation bench scale data on the separate GRG and non-GRG fractions is required, the simplified test combines the advantage of lower mass requirements, lower costs and fresher surfaces.
Table I – Advantages and Disadvantages of the One-Stage Simplified GRG Test

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Smaller mass easier to obtain for greenfield projects</td>
<td>The nugget effect is increased for low grade or coarse gold ores</td>
</tr>
<tr>
<td>The test requires less resources to complete</td>
<td>The GRG liberation profile is lost</td>
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<tr>
<td>The test is more likely to be completed at the mine site</td>
<td>Some information on the GRG size distribution is lost both at the fine and the coarse end</td>
</tr>
<tr>
<td>The fresher surfaces make it easier to combine the test with flotation testing</td>
<td>Abrasive ores return a low and finer GRG value</td>
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**Marginal GRG**

GRG is recovered at a rotation velocity that correspond to a theoretical acceleration ranging from 55 Gs at the surface of the lowest groove of the Knelson Concentrator Model MD3 to 70 Gs at the surface of the top groove. Figure 6 shows the cumulative recovery retained (a measure of marginal GRG content) for the GHA ore sample. Recovery was achieved with a Falcon SB50 semi-continuous Concentrator, operating at a theoretical 180 Gs. Clearly the marginal GRG is largely below 20 µm.
Rowland (3) used a vapour-pressure scanning electron microscope (VP-SEM) to examine the marginal GRG recovered from the non-GRG component of the GUY1 sample. Marginal GRG had been recovered using three semi-continuous centrifuge units operated at respectively 60, 155 and 180 theoretical Gs. The minus 20 μm and 20-25 μm fractions of the concentrates were first upgraded by digestion with HF. Gold-bearing particles were then identified in the back-scattered mode and photographed. The use of the VPSEM made it possible to examine the sample without preparing a polished section with minimum surface charging. Particle size was characterized in two dimensions using the major and minor axes of each particle, the first being the largest dimension of the particle and the latter being the largest dimension perpendicular to the first. Figure 7 shows the cumulated retained size distributions thus obtained. Results show that the size distribution of the marginal GRG gets progressively finer at the centrifuge force used increases from 60 to 180 Gs. The dimension of the minor axis is largely below 10 μm at 180 Gs, whereas it is above 10 μm at 60 Gs. The major axis shows a wider range (this was expected) that reflects the presence of flakes and elongated particles along that of stubby and almost spherical particles. These results open the door to the recovery of finer gold particles than what is normally practised in primary grinding circuits, using much higher rotating velocities. Anecdotal evidence from plants where this is practiced, typically in regrind circuits, suggests both possibilities and difficulties. Further work is planned in this area.
The only outcome of this work presented here will be the additional insight gained into GRG classification. Early plant sampling in Canada and elsewhere had characterized the classification of GRG, but the range of cut-size was too narrow to establish a definite link between classification of GRG and that of its gangue. Figures 8a and 8b show part of the extended database; all coarse classification curves were extracted from the plant audits performed during the project. The general ordering of the curves is similar for both GRG and gangue. Some uncertainty at very fine size is observed. A general relationship was developed between the partition curve of GRG and that of the ore and validated with data collected from other sites. Figure 9 shows that the relationship is satisfactory down to 37 µm, with some deviations below 37 µm. Such deviations may be linked to the difficulty of measuring GRG content below 37 µm, particularly for coarser products –i.e. products with a significant gangue content between 300 and 850 µm. In practice, the bulk of gravity recovery comes from GRG coarser than 37 µm, because GRG finer than 37 µm is difficult to recover by gravity and reports to cyclone overflows much more readily than its coarser counterpart. Thus the uncertainty below 37 µm has relatively little impact on the overall accuracy of the model.
Figures 8a and 8b – Comparing Partition Curves of Ore (A) and GRG (B)
WEB-BASED SIMULATOR

A simulator accessible via the web was developed for sponsors. The simulator, based on Laplante et al. (4), uses GRG data, grinding circuit data (e.g. partition curves), Knelson-based gravity recovery and user-specified gold room recovery to predict gravity recovery as a function of the proportion of the circulating load treated, for Knelson Concentrator-based gravity circuits. As more of the circulating load is treated, the number of recovery units needed also increases, and the best combinations of CD20, CD30, or XT48 units are suggested for each circuit size. The rationale behind the offering a range of circuit options for the user to quickly realize that the link between the recovery effort and the total amount of GRG recovered is highly non-linear. By matching design and operating costs to the predicted amount of gold recovered, the user can approach the optimum economic size of the gravity circuit (Laplante and Xiao, 5).

Figure 10 shows a typical input screen, and Figure 11 a typical output screen. The active cells of Figure 11 yield another result pane with the GRG size distribution of the cyclone underflow and overflow. The latter will eventually be linked with the SIMCIL web-based simulator of the A.J. Parker Cooperative Research Centre for Hydrometallurgy.
Further expansion of the simulator is planned, including the addition of other recovery units, such as Falcon Concentrators, InLine Pressure Jigs, and flash or contact cells. The use of the simulator as a diagnostic tool for troubleshooting gravity circuits will also be explored.
THE LINK BETWEEN GRAVITY RECOVERY AND CYANIDATION KINETICS

This link has been addressed before by the authors (Laplante and Staunton, 6). At one sponsor’s site, the gravity circuit was shut down for 24 hours to assess the effect of gravity recovery on leach circuit performance. Sampling of the cyclone overflow (COF) and cyclone underflow (CUF) was undertaken shortly before shutting gravity down and at regular time intervals whilst the circuit was shut down. Figure 12 summarises how the total and gravity-recoverable gold content of the COF and CUF with and without the gravity circuit running (Bax and Staunton, 7). The following observations were made:

- The total amount of gold in the COF is equal to the head grade in the absence of gravity. This amount drops by one third when the gravity circuit is operating, which is consistent with the observed gravity recovery.
- Most of the additional gold reporting to the COF in the absence of gravity is gravity recoverable. A small increase in non-GRG is also observed, which is consistent with the observation that grinding circuits transform some of the GRG into non-GRG.
- The difference in the CUF gold content is entirely due to the GRG content.

Figure 12 – Gold Content in the Cyclone Overflow and Underflow with and without Operation of the Gravity Circuit

Figure 13 illustrates the cyanidation kinetics of COF samples taken with and without the gravity circuit. The difference is striking: cyanidation kinetics is much slower when the gravity circuit is not operating. The response curves were fitted to slow and fast first-
order kinetics response curves (first-order kinetics is not the actual order of the reaction, but a manifestation of the size distribution of the gold particles), and the following observations were made:

- The fast kinetics proportion is similar for both products, and corresponds roughly to two thirds of the non-GRG in the COF.
- The slow-kinetics proportion is slightly lower than the GRG content for both products.
- The grade of the cyanidation residue is equal to 0.18 g/t for both samples.

![Figure 13 – Recovery as a Function of Cyanidation Time for the COF With Gravity (Left) and Without Gravity (Right)](image)

Whilst it is not claimed that the cyanidation kinetics observed at laboratory scale represents exactly what is observed at plant scale, recent increases in gravity recovery at the site (up to 50% relative) have been matched by significant increases in overall recovery (Price, 8).

**CONCLUSIONS**

Collaborative research efforts such as the AMIRA P420B project are able to provide significant research outcomes at modest cost to individual sponsoring companies. Many facets of a complex problem can be simultaneously addressed. The first pole of the triangle shown in Figure 1 benefited strongly from laboratory research work; whereas the site surveys generated much of the information needed to link the partition curve of GRG to that of the ore. This is already proving invaluable for at least two important applications, namely the design of gravity circuits for greenfield
applications, for which a simulated mass balance of the grinding circuit is usually available, and for optimization of existing gravity circuits with minimum data, typically a GRG size distribution and a sized mass balance of the grinding circuit (without gold assays).

A second important trend emerged from the gravity research: most circuit audits identified simple corrective actions that could increase gravity recovery. Such actions, when implemented, resulted in significant increases in gravity recovery and measurable increases in overall recovery. In one plant, a combination of improved gravity recovery and the introduction of unit flotation in the primary grinding and regrind circuit achieved increases in overall recovery in excess of 2%.

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