A GRAVITY RECOVERABLE GOLD AUDIT OF HARTE GOLD CORP'S SUGAR ZONE MILL IN NORTHERN ONTARIO

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ABSTRACT

An audit of Harte Gold's Sugar Zone mill was undertaken to evaluate the performance of the overall circuit with respect to gold recovery. The Sugar Zone mill achieves some the highest gravity recoveries amongst Ontario gold mines utilizing a gravity-flotation flowsheet with two Falcon semi-batch gravity concentrators processing the entire mill discharge and gravity concentrates being upgraded by a Holman shaking table for refining on site. Flotation concentrates are transported off site for smelting.

A thorough sampling campaign was carried out in November 2019 and a series of Detailed Gravity-Recoverable-Gold (DGRG) tests and size-by-size gold assays were performed on the samples. Sugar Zone ore collected during the audit was determined to contain 71.4% gravity recoverable gold (GRG) which was found to be moderately coarse in comparison to other ores. The actual gold recovery at the plant was 95.0%, with 70.3% recovered to gravity bullion plus 24.7% to flotation concentrate.

A proprietary mathematical model was used to benchmark the gravity circuit performance. The model was found to be in good agreement with the measured plant performance and suggested that the gravity circuit was operating well but less than ideal hydro-cyclone classification efficiency was allowing fine GRG to escape the grinding/gravity circuit. The model predicted that by improving the hydro-cyclone efficiency the gravity gold recovery rate could be increased form 70.3% to 72.8%.

Finally, payment terms for gravity bullion and flotation concentrate were compared and a sensitivity analysis was completed to demonstrate the impacts on concentrate grade dependent net payables.

KEYWORDS

Gold recovery, Gravity recoverable gold (GRG), Gravity recovery, Plant audit, Cyclone efficiency, Falcon Concentrator, Shaking Table

INTRODUCTION

The profitability of a mining operation depends on maximizing metal recoveries while minimizing operating costs. Strategies to meet this objective require obtaining quantitative information at steady-state plant operation and then efficiently using this information to optimize plant performance. (Deepak, 2015)

Plant optimization starts with a plant audit. The benefits of plant auditing can be significant and the learnings often result in measurable improvements to recovery, grade, throughput and/or decreased operating cost.

Harte Gold Sugar Zone Mine

The Sugar Zone Mine entered commercial production in 2019 and has an anticipated mine life of approximately 13 years at current production levels. The mine is currently producing from the Sugar Zone North and South areas. Development is underway to the Middle Zone, which will open up a whole new mining area, expected by mid-2021.

The Sugar Zone Deposit is interpreted as an orogenic, mesothermal gold deposit located in a zone of high strain within the Dayohessarah Greenstone Belt. Gold mineralization occurs in quartz veins, quartz stringers and quartz flooded zones predominantly associated with narrow porphyry sills, porphyry contact zones, hydrothermally altered mafic metavolcanics and, rarely in weakly altered mafic metavolcanics. Fine to coarse-grained specks of visible gold are common in the Sugar Zone quartz veins, usually occurring within marginal, laminated or refractured portions of the veins. Quartz veins and silicified rocks also contain varying amounts of pyrrhotite, pyrite, chalcopyrite, galena, sphalerite, molybdenite and arsenopyrite, totaling 1-3% sulfide content in ROM ore.

The Sugar Zone Mill utilizes a conventional Gravity-Flotation flowsheet, with gravity concentrate refined to bullion on site and sulfide flotation concentrate shipped in bulk to a copper smelter.

MILL PROCESS DESCRIPTION

The Sugar Zone mill consists of a jaw and cone crusher preparing ball mill feed at -0.5” crush size. The gravity circuit within the grinding circuit consists of two Falcon SB1350 concentrators treating 100% of the mill discharge and operating at 60G - 90G and 20-45 min cycle time. Falcon Semi-Batch (SB) concentrators are specifically designed to recover precious metals that occur in the free, metallic state. This type of application requires very high concentrating ratios and consequently very small mass yields to concentrate, usually < 0.1%. In the Gold Room, the Falcon concentrate is subjected to further dressing using low intensity magnetic separation ahead of a Holman 2000 shaking table with the table concentrate removed at a high enough grade for smelting and the table tailings recirculated back to the grinding circuit.
Rougher flotation concentrate is produced from tank cells. The magnetic/ferrous stream from the gold room is combined with the flotation concentrate. This paper focuses on evaluating the performance of the gravity circuit including hydro-cyclones, centrifugal concentrators and shaking table with respect to gravity gold recovery.

Figure 1. [Left] 2x Falcon SB1350 treating 100% of mill discharge; [Right] Holman 2000 shaking table in the gold room

AUDIT SAMPLING CAMPAIGN

In consultation with Sepro Mineral Systems, the sampling campaign was supervised and executed by the Sugar Zone mill personnel over a period of 3 days in November 2019. The circuit sampling locations are highlighted (yellow) in the following simplified flowsheet (Figure 2).

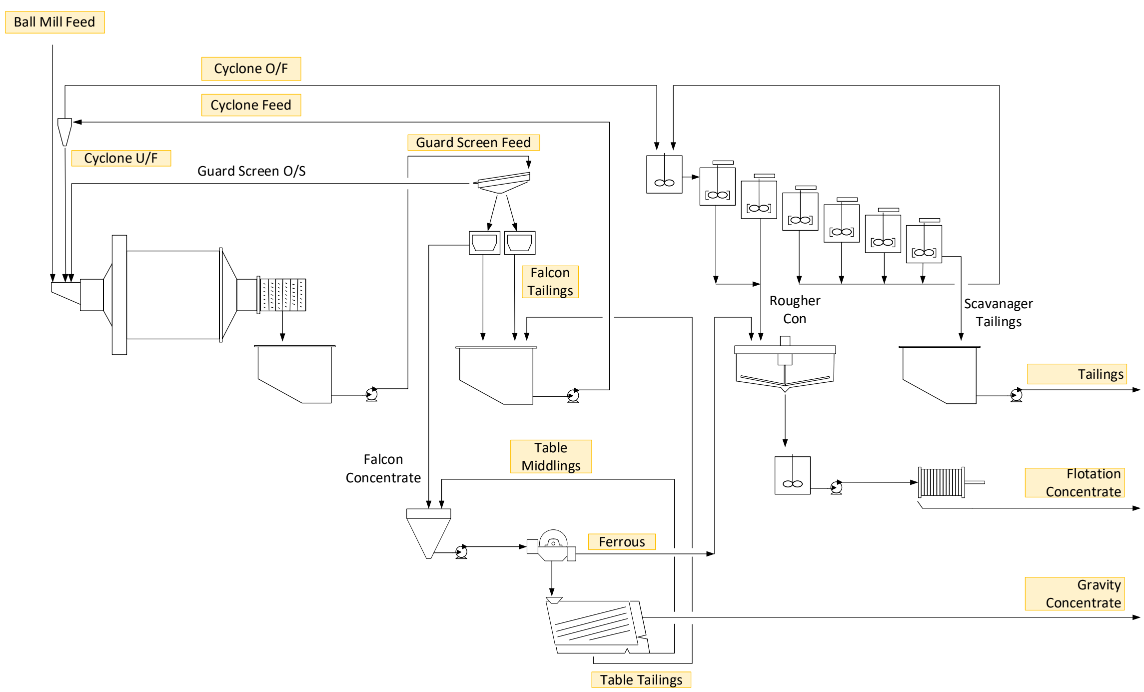

Figure 2. Simplified Flowsheet of Sugar Zone Mill with Sampling Points

The audit samples were collected on an hourly basis during dayshifts for a total of 26 rounds of sampling. The hourly samples from each sampling point were subsequently combined to form a 3-day composite for the audit sampling program. The respective tonnage and flowrates of each stream were also recorded during the sampling period.

All testwork on audit samples was performed by Met-Solve Laboratories while test product assays were performed by Harte Gold and Actlabs.

AUDIT RESULTS

Detailed GRG TEST

The gravity-recoverable-gold content of an ore, as obtained via a GRG test, provides a quantitative theoretical limit of gold that can be recovered using a batch centrifugal concentrator. The test itself consists of a sequential liberation via grinding followed by gravity concentration using a lab scale centrifugal concentrator such as the Falcon L40 (Figure 3). The concentrates and the final tailings products are screened and assayed by size fractions. The progressive grind approach limits the smearing of gold onto grinding media and allows for the recovery of GRG as it becomes liberated. The results from the test are presented as a cumulative GRG distribution as well as GRG distribution by particle size class. (Grewal, 2009)

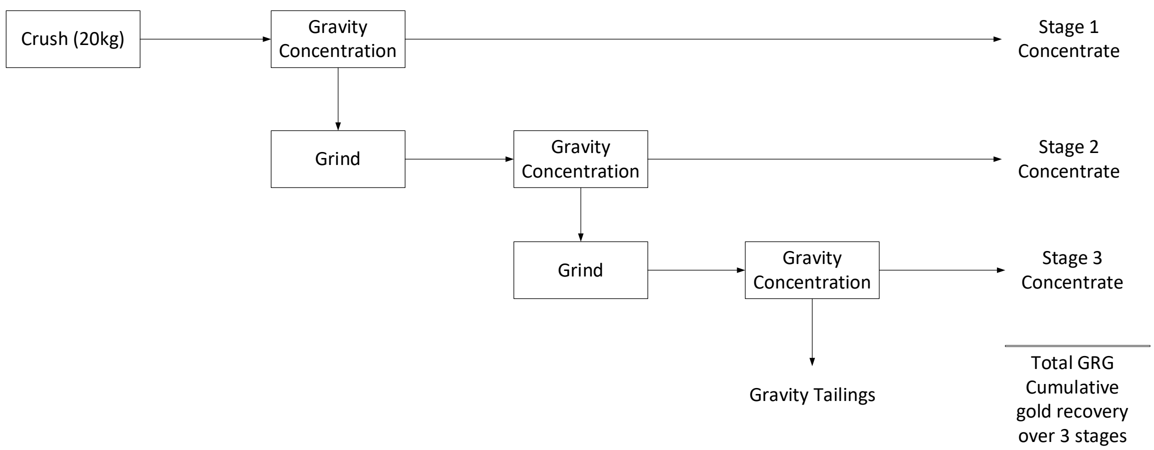

Figure 3. Standard procedure for a GRG test using a semi-batch centrifugal gravity concentrator

Gravity Circuit Feed Characterization

A Detailed Gravity-Recoverable-Gold (DGRG) test was performed on 20 kg of the Ball Mill Feed (BMF) sample. The results from this test were used to characterize and identify the baseline GRG content of the ore. These results were incorporated into the model to predict the expected gold recovery by the gravity circuit for comparison with the actual gravity circuit gold recovery.

This test found that the feed ore had a GRG value of 71.4% from a calculated head grade of 5.64 g/t, at a grind p80 = 99 μm, which matches the measured plant particle size at the cyclone overflow (p80 = 100 μm). The cumulative particle size classification of the GRG on the BMF material is shown graphically in Figure 4. The shape of the curves indicate that the GRG from the Sugar Zone Mine is moderately coarse in particle size.

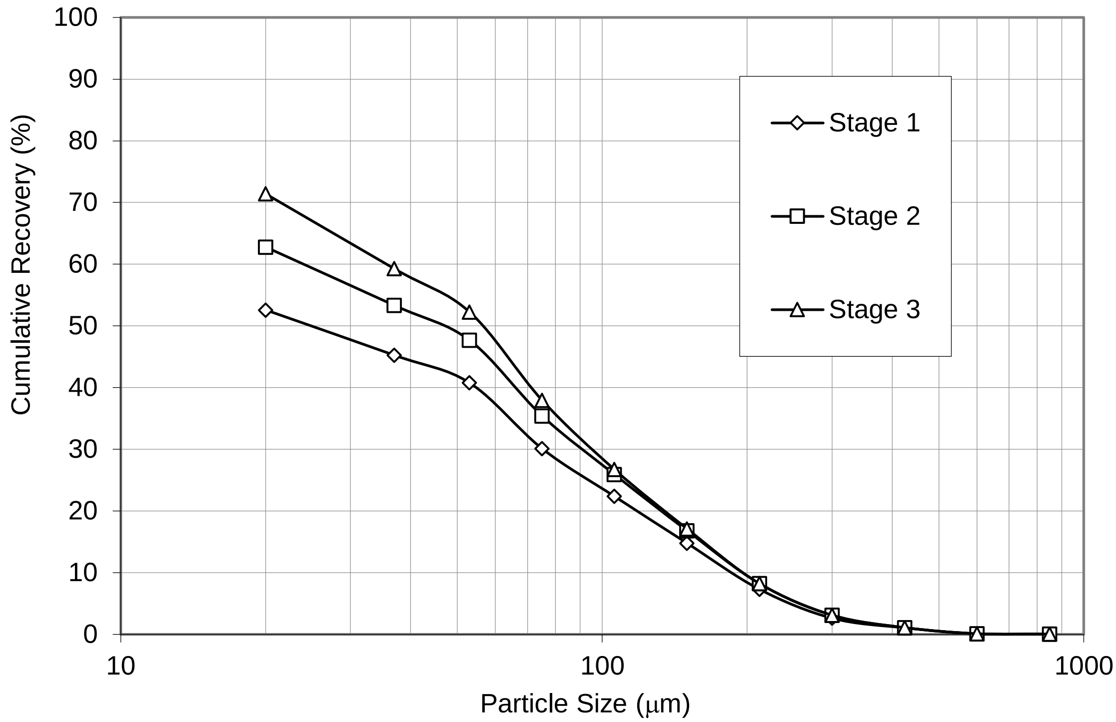

Figure 4. Cumulative GRG recovery as a function of particle size on the BMF sample

Hydro-cyclone Performance

The efficiency of the hydro-cyclone in retaining GRG within the grinding circuit is a key contributing factor to effective operation of centrifugal concentrators (Banisi, Laplant and Marois, 1991) because batch centrifugal concentrators fed at high tonnages and high pulp densities have a relatively low single pass recovery rate and therefore rely on GRG being retained within the circulating load by the hydro-cyclone, thereby effectively creating a multiple pass environment. The performance of the cyclone can be evaluated by comparing the GRG content of the cyclone feed (C-Feed), cyclone underflow (C-UF) and cyclone overflow (C-OF). The tonnage, gold grade and GRG content for the respective cyclone streams are summarized in Table 1 and the calculated gold retention efficiency is presented in Table 2.

Table 1. Cyclone Stream Data

Cyclone Data	**Tonnage (t/hr)**	**Au Grade (g/t)**	**GRG (%)**
Cyclone-UF	78.9	6.98	64.7
Cyclone-OF	31.6	2.37	34.6
Cyclone-Feed	110.4	5.95	68.3
Calculated Cyclone-Feed	110.4	5.66	61.1

Table 2. Cyclone Efficiency in Retaining Gold Content within Grinding Circuit

Determination Method	**Cyclone Eff. In Retaining Gold (%)**	
	Total Gold to U/F	**GRG to U/F**
Using Calculated Cyclone-Feed	88.0	93.2
Using Cyclone-Feed	88.6	94.2

The circulating load of the grinding circuit was determined as 250%. The cyclone partition curve for GRG retention is shown in Figure 5. The curve shows high retention efficiency of the GRG in the +212 µm fractions, leading to a gradual decrease below 150 µm, followed by a sharp drop in GRG retention in the -53 µm fractions.

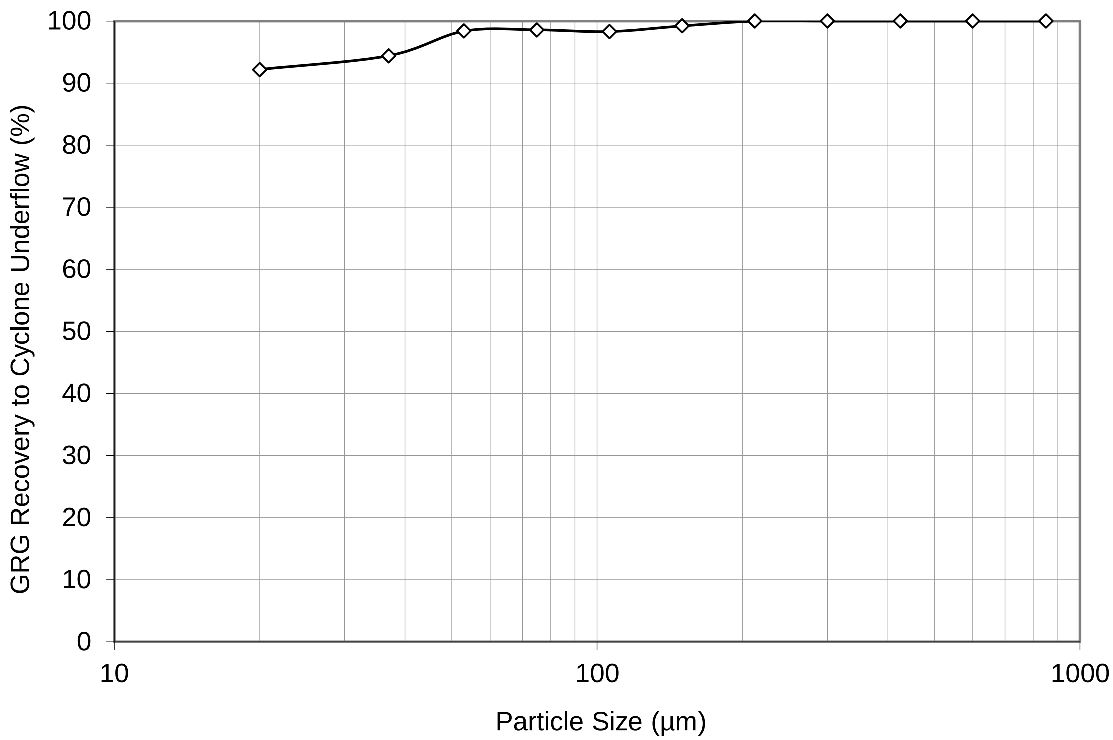

Figure 5. GRG recovery to cyclone underflow as a function of particle size

The calculated cyclone efficiency in retaining GRG within the grinding circuit - measured at 93.7% - is relatively low, which allows a portion of the fine GRG to exit the grinding circuit before it can be recovered. An efficient hydro-cyclone is expected to retain 95-99% of GRG.

The efficiency of the cyclone is also evaluated by its particle size partition (Tromp) curve. The particles size analysis for the corrected curve is:

- D75 = 120 µm
- D50 = 75 µm
- D25 = 43 µm
- S_h = 0.36 (Sharpness of Separation)
- I = 0.52 (Imperfection Factor)

The Tromp curve of the cyclone is presented in Figure 6.

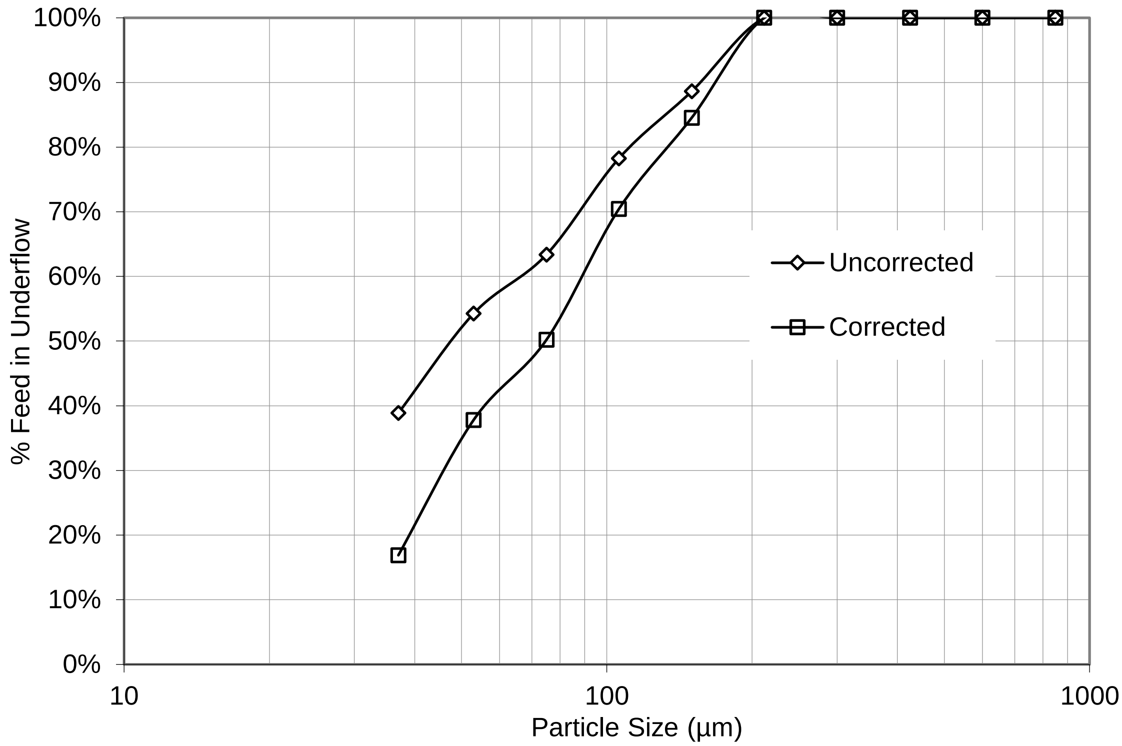

Figure 6. Tromp curve for hydro-cyclone

The results indicate that the cyclone is operating within the medium-to-poor efficiency range. Ideally, the cyclone would have an imperfection factor of < 0.4. (Murthy and Basavaraj, 2012) and increased cyclone efficiency would be expected to result in measureable improvements to the grinding and gravity circuit performance.

Gravity Circuit Performance

The performance of the gravity circuit was evaluated by its input (Guard Screen Feed) and outputs (combined Falcon Tailings and Table Tailings represent the Cyclone Feed stream). Detailed Gravity-Recoverable-Gold (DGRG) tests were performed on 20 kg of both streams. Table concentrate weight and grade was extrapolated from refinery data. Ferrous and other shaking table outputs were timed measurements with assays on a representative split of the sample. Any gold within the gold room would be considered gravity recoverable (GRG).

The GRG recovery by the gravity circuit as a function of particle size is illustrated in Figure 7. Overall, the gravity circuit recovered 70.3% of total gold as gravity bullion and 2.7% as entrained or smeared onto ferrous, which gets added to the flotation concentrate. As it can be seen that the coarse gold recovery rate is high, recovering 99% of the +150µm size fraction, dropping slightly to 95% in the +53µm to -150µm range, then to 64% in the -37µm range.

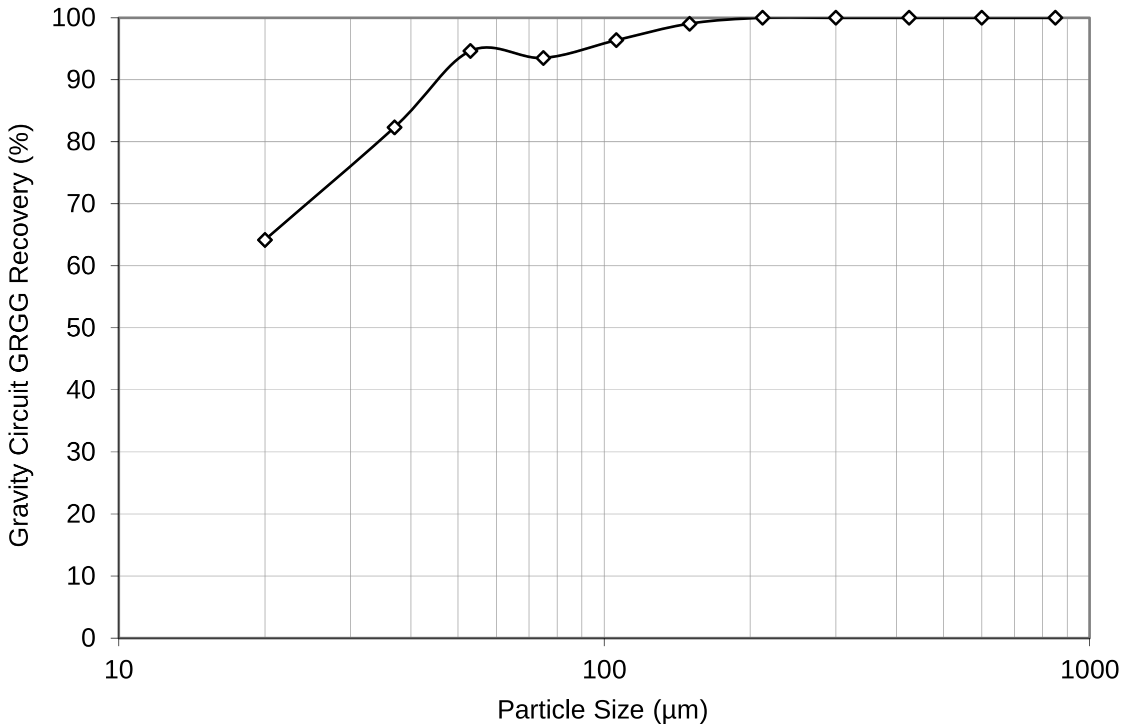

Figure 7. GRG recovery of the gravity circuit as a function of particle size

The metallurgical balance of the gold room streams is summarized in Table 3. 3.0% of the gold collected by the Falcon Concentrators is diverted to the flotation concentrate via the ferrous stream, 77.4% is recovered to the table concentrate, 19.6% exit the gold room as table tailings returning to the grinding circuit. The table feed rate equals 167.8% of the Falcon Concentrate due to the recirculation of middlings to the table feed tank.

Table 3. Summary of Gold Room Balance

	Tonnage (24h basis)	**Total Au = GRG**	
Stream	**(tph)**	**Grade (g/t)**	**Dist'n relative to Falcon Con (%)**
Ferrous	0.004	1,195	3.0
Table Concentrate	0.000167	750,000	77.4
Table Middlings	0.008	16,400	81.1
Table Tailings	0.0589	539	19.6
Calculated Falcon Conc.	**0.0631**	**2,956**	**100.0**
Calculated Table Feed	**0.0671**	**4,664**	**167.8**

Flotation Circuit Performance

The performance of the flotation circuit was determined by the metallurgical balance between the flotation concentrate and tailings, as summarized in Table 4.

Table 4. Stage Recovery of Gold from Flotation Circuit

Products	**Tonnage (tph)**	**Grade (g/t)**		**Distribution (%)**	
		Total Au	**GRG**	**Total Au**	**GRG**
Flotation Concentrate	0.6	68.59	20.3	81.3	90.8
Flotation Tailings	31.0	0.29	0.04	18.7	9.2
Calculated Float Feed	**31.6**	**1.52**	**0.40**	**100.0**	**100.0**

The results show that flotation recovered 81.3% of the total gold from the cyclone overflow stream. With the gold room ferrous stream included in the final flotation concentrate the flotation concentrate grade increases to 76.45 g/t Au.

Overall Plant Performance

Gold deportment between plant outputs is summarized in Table 5: Based on total gold outputs, 70.3% reported to gravity bullion and 24.7% to combined flotation concentrate, leaving 5.0% to tailings. Based on GRG, 87.7% reported to gravity bullion and 11.5% to combined flotation concentrate, leaving 0.8% to tailings.

The metal recovery based on plant outputs is 95.0% for total Au and 99.2% GRG. The data reconciled well with the calculated recoveries from the Ball Mill Feed and Final Tailings assays, which suggested 94.9% for total Au and 99.1% for GRG.

Table 5. Summary of Overall Plant Performance, Exit Streams Only

Product Stream	**Tonnage (tph)**	**Grade (g/t)**		**Distribution (%)**	
		Total Au	**GRG**	**Total Au**	**GRG**
Table Con / Bullion	**0.000167**	**750,000**	**750,000**	**70.3**	**87.7**
Ferrous	0.004	1,195	1,195	2.7	3.4
Flotation Concentrate	0.57	68.6	20.3	22.0	8.1
Flotation Con + Ferrous	**0.574**	**76.5**	**28.5**	**24.7**	**11.5**
Final Tailings	**31.0**	**0.29**	**0.04**	**5.0**	**0.8**
Calc Ball Mill Feed	**31.6**	**5.64**	**4.5**	**100.0**	**100.0**

GRAVITY CIRCUIT MODELLING

Considerable research has been done (Banisi, Laplante and Marois, 1991) to develop a fundamental understanding of gravity gold recovery from within grinding circuits; much of the research work was done by Dr. André Laplante of McGill University in Canada.

The key factors affecting gravity recovery of gold from within grinding circuits are:

- the gravity-recoverable-gold (GRG) content of the ore
- the size distribution of the GRG
- the recovery efficiency of the gravity concentration circuit including gold room
- the cyclone efficiency (as defined by the partition curve of GRG)
- the fraction of the circulating load treated by the gravity concentrator
- the amount of GRG converted to non-GRG in the grinding mill (grinding behaviour of the gold)
- the gravity circuit availability

Sepro Mineral Systems has developed an advanced mathematical model that incorporates these key factors. The model not only helps to predict gravity gold recovery for new installations but can also assist in trouble shooting existing circuits. The basic version of the model utilizes bulk GRG data, cyclone efficiency and stage recovery of the centrifugal gravity concentrator, while a more detailed approach includes size-by-size data.

A sensitivity analysis from modeling provides insights to the effects of various parameters on gold recovery and demonstrates that effective recovery of gold relies strongly on the efficiency of the cyclone at retaining GRG within the grinding circuit. Poor partition behaviour of the cyclone or upsets in the cyclone feed stream can significantly reduce gravity gold recovery.

The results from the gravity circuit model are presented in

Figure 8. The two plots represent cyclone efficiencies of 93.7% (measured) and 99.0% (optimum). It is important to note that the initial slope of the GRG recovery curve is significantly steeper for highly efficient cyclones, which is particularly relevant to applications where only a small fraction of the circulating load (i.e. 20%) gets treated by gravity. The actual amount of the circulating load treated is dictated not only by metallurgical requirements but also by economical and practical considerations. The Sugar Zone mill treats 100% of the circulating load.

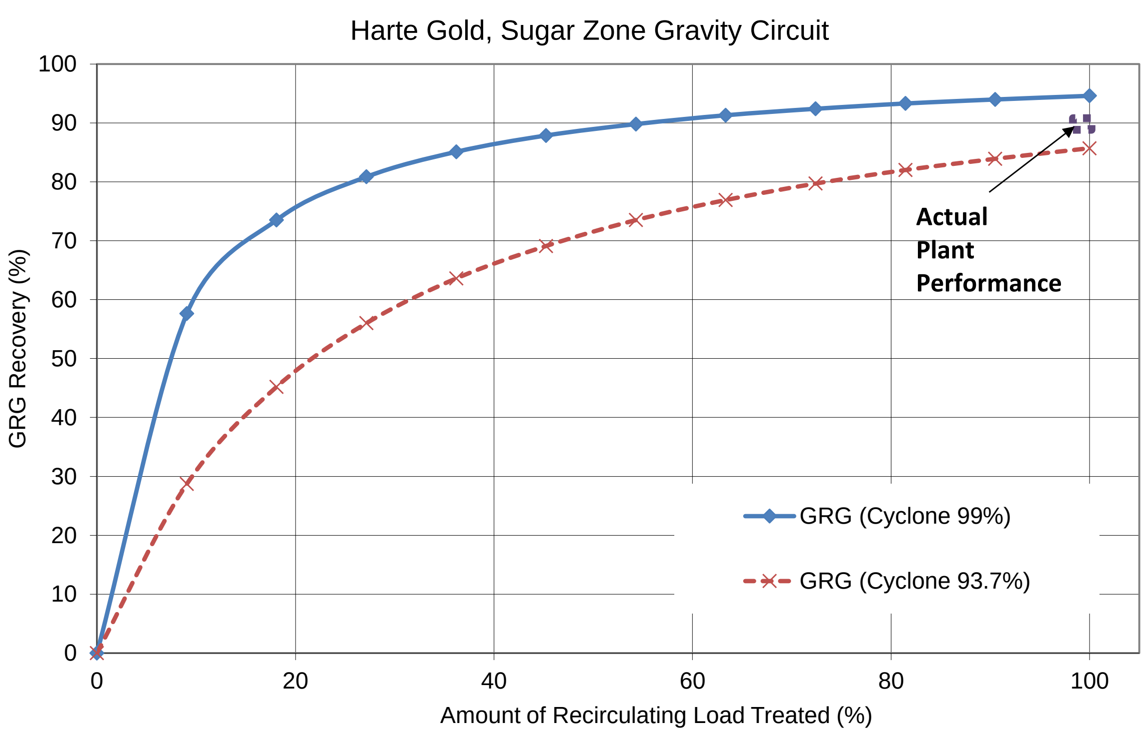

Figure 8. GRG recovery as a function of % of recirculating load treated by gravity

Modelling with the measured cyclone value matches relatively well with the actual plant performance: The GRG recovery predicted by the mathematical model was 85.7%, while the actual plant recovery rate was 91.1% of GRG. According to the model, a maximum recovery rate of 94.6% of GRG is possible with an optimal hydro-cyclone.

ECONOMICS COMPARISON BETWEEN BULLION AND CONCENTRATE

The benefits of installing gravity concentrators within the grinding circuit are:

- An increased overall metal recovery by recovering GRG at a coarse size while minimizing the breakage of GRG into fines smaller than 10µm which are not recovered efficiently by flotation (Fullam, 2010); According to Dr. André Laplante (Laplante, 2005) the benefit for every 10% of recovery by gravity usually falls in the range of +0.5-5% of additional overall gold recovery. Since no plant data exists for operating the mill without gravity, it is assumed for the economic sensitivity analysis that the overall plant recovery increases by 1% for every 10% gravity recovery.

- Favorable payment terms when precious metals are sold as bullion as opposed to bulk flotation concentrate. The economics for the sale of gold in bullion and flotation concentrate from the Sugar Zone Mine are explained below. Cash flow is also favorable for bullion since payments for bullion are received quicker, i.e. weekly, as compared to payments for bulk concentrate, i.e. monthly.

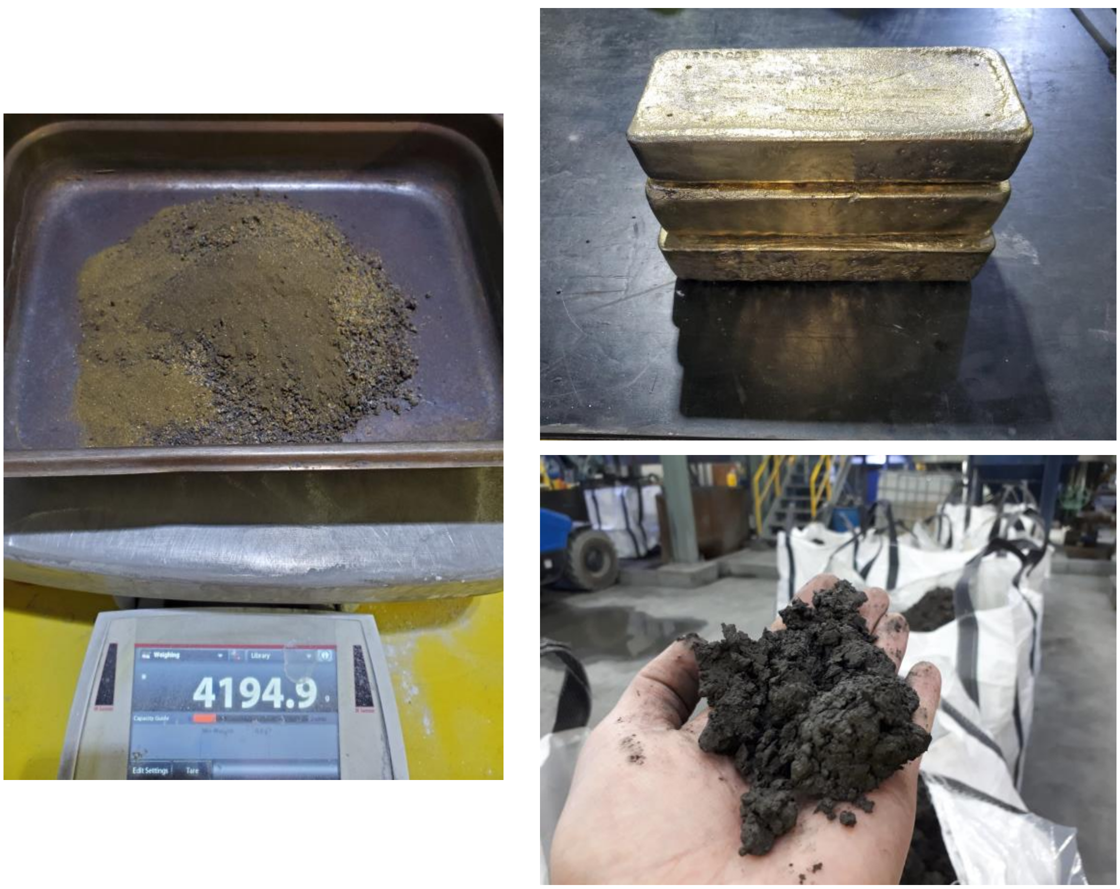

Figure 9. [Left] Shaking Table Concentrate (approx. 75% Au); [Right Top] Gravity Bullion (approx. 80% Au); [Right Bottom] Filtered Flotation Concentrate (approx. 75 – 125 g/t Au)

Bullion from Gravity Concentrate

Based on a typical bullion shipment of 750 ounces, the charges, penalties and payables per ounce of gold are presented in Table 6 and can be calculated as: $2.95 (Transport) + $1.60 (Refining) + $ 0.65 (Representation/Assay) + 0.80 (non-payable) = $ 6.00 USD per ounce Au;

At a gold price of $1,700 USD per ounce, the resulting net payable is $1694.00 USD per ounce for bullion.

Table 6: Associated Costs for the sale of Bullion

Transportation	$ 2,200	USD/shipment
Refining	$ 1,200	USD/shipment
Representation/ Assay	$ 480	USD/shipment
Payable Terms	99.95%	

Flotation Concentrate

Payables for bulk sulfide flotation concentrate depend on the concentrate grade. The charges, penalties and payables per ounce of gold in flotation concentrate are presented in Table 7 and can be calculated as: $41.50 (Transport) + $73.25 (Treatment) + $2.25 (Moisture) + $14.00 (Refining) + $68.00 (non-payable) = $ 199.00 USD per ounce Au;

At a gold price of $1,700 USD per ounce, the resulting net payable is $1501.00 USD per ounce for the flotation concentrate.

Table 7. Associated Costs for the sale of Flotation Concentrate

Transportation	$ 102.00	USD/dmt
Treatment	$ 180.00	USD/dmt
Refining + Assay Charge	$ 14.50	USD/payable oz Au
Moisture Penalty	$ 5.60	USD/dmt/(1% moisture > 10%)
Typical Moisture Content	12%	
Payable Terms		
<50g/t	93%	
50g/t - 75g/t	95%	
75g/t - 100g/t	96%	Note: 76.5 g/t Au at time of audit
>100g/t	96.5%	

Considerations about Gravity Recovery and Flotation Concentrate Grade

The audit of the Sugar Zone mill determined that the gravity circuit is operating near optimum performance with 70.3% of total gold recovered to gravity bullion. An increase in the hydro-cyclone GRG retention efficiency up to 99.0% is expected to produce a further increase in gravity recovery, allowing for up to 72.8% of total gold recovered to gravity bullion, for which favorable payment terms are in place.

However, shifting more gold from flotation concentrate to gravity results in an inevitable reduction in flotation concentrate grade since bulk sulfide flotation mass yield is primarily governed by sulfide content and not gold content. Payables for flotation concentrate depend on the concentrate grade. Figure 10 demonstrates net payables and sales revenue for bullion and concentrate as a function of GRG recovery. At the time of the audit, flotation concentrate was recovered and shipped at 76.5 g/t. Improvement efforts to the gravity recovery circuit should consider that optimum combined sales revenues require maintaining the flotation concentrate grade above 75 g/t due to payable terms stepping from 96% to 95%. The graph indicates that a dip in combined sales revenues is to be expected if the concentrate grade assays below 75 g/t.

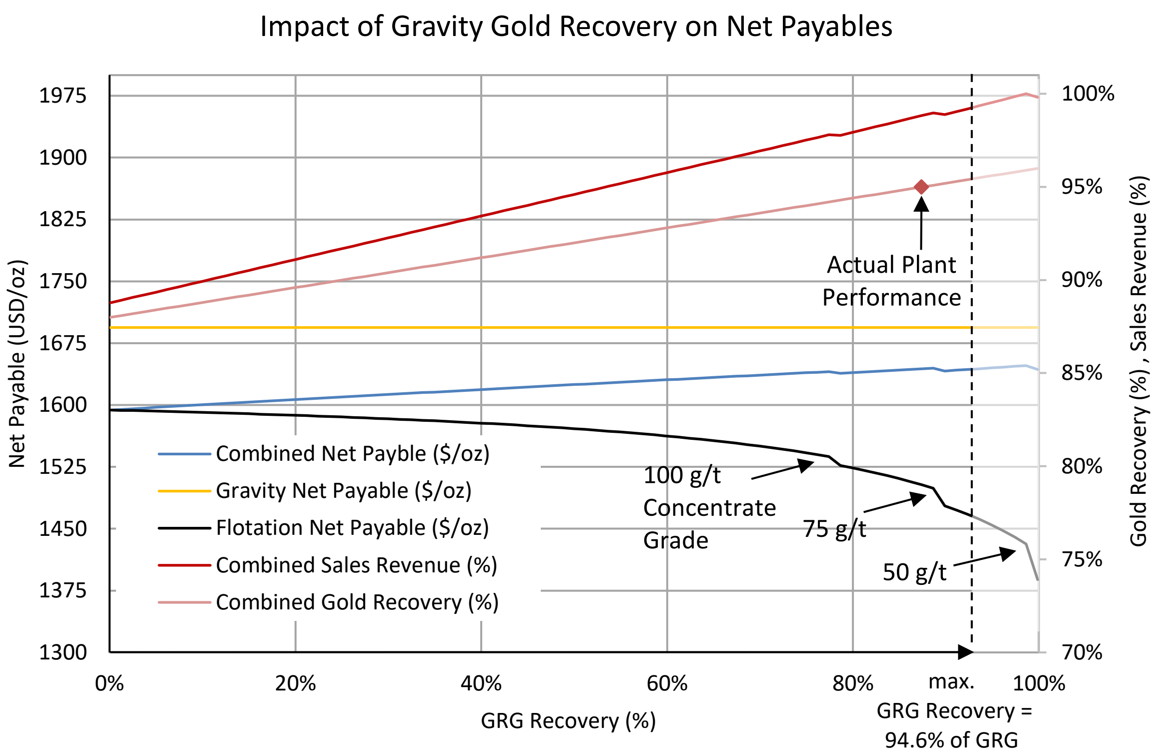

Figure 10. Net Payables as a function of gold recovery by gravity

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SUMMARY

The audit of Harte Gold's Sugar Zone mill shows that the gravity circuit is performing near optimum efficiency.

Sugar Zone ore contains moderately coarse gravity recoverable gold with a GRG value of 71.4%. The measured overall gold recovery at the plant was 95.0%, breaking down as 70.3% in gravity bullion plus 24.7% in bulk sulfide flotation concentrate. A proprietary mathematical model was used to benchmark the mill performance and the model was found to be in good agreement with the measured plant performance. The model suggested that the gravity circuit was operating well but less than ideal hydro-cyclone classification efficiency was allowing fine GRG components to escape the grinding circuit.

Further improvements of gold recovery to gravity would require better hydro-cyclone efficiency at retaining GRG within the grinding circuit. The model predicts that improving cyclone efficiency from 93.7% to 99.0% in retaining GRG within the gravity circuit would lead to an increase from 70.3% to 72.8% gold recovery towards the gravity bullion.

The comparison of payables for gravity bullion and flotation concentrate shows that bullion generates favorable net payables and faster cash flow. However, it was found that overall economics are at an optimum only if the flotation concentrate grade can be maintained above 75 g/t, which should be considered in optimization efforts of gravity gold recovery from the grinding circuit.

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