PAPER X

Effect of Gravity Recovery on Overall Plant Recovery Sadiola – A Case Study

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ABSTRACT

An enhanced gravity concentrator was installed in conjunction with an Intensive Leach Reactor at the Sadiola plant in Mali last year and commissioned in Dec 2007.

There has been much debate over the years as to the effect of gravity concentration on overall plant performance. The late Dr Laplante suggested that for every 10% of gold recovered by gravity, there was a corresponding 0.1% to 1% additional overall plant recovery. The results at Sadiola are consistent with this hypothesis with an overall 4% gain in plant recovery.

With total gold recovery of 12% in the gravity section, grades are increased from 3.54g/t in the gravity feed to an average of 2 600g/t in the concentrator feed to the in-line reactor. The recovery of gold in the in-line reactor is in excess of 98.5%.

This paper discusses the background to the project, the laboratory testwork prior to the equipment selection, the operational results of the system, as well as the benefits of the future application of high mass yield centrifugal concentrators in base metals, sulphides and industrial minerals. Bench scale, pilot scale and plant practice examples are also presented.

INTRODUCTION

Besides picking nuggets off the ground or out of riverbeds, gravity concentration is arguably one of the oldest methods of recovering gold. In circa 6000BC people discovered that gold can be found behind the rocks and in depressions of creek beds. By placing rocks in a stretch of channel with the proper slope the first sluice is built, probably around 4,000 BC, and this method is still practiced today.

ANCIENT EGYPTIAN WASHING TABLE

Circa 3000 BC, the Egyptians mined rock from underground, pulverized it and use a steeply sloped rock bed with water flow to concentrate gold, giving mankind the first metal mine and mill operations. The use of wood and later metal to form rifles and a box to put them in made the sluice portable or it could be made from local materials. One interpretation of the legend of the Golden Fleece is that comes from the practice of lining the sluice bottom with sheep hides.

Gold Recovery utilising enhanced gravity

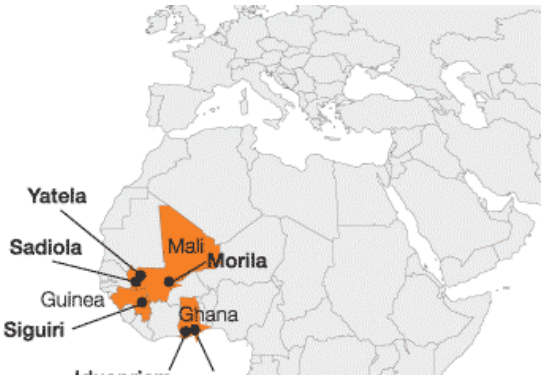
Over the years, the advancement in equipment design and the ever increasing pressure by environmentalists has increased the popularity of gravity concentration. Batch centrifugal gravity concentrators, which produce very high ratios of concentration, have become commonplace for recovering free gold within milling circuits. Their effectiveness has proven to be especially useful in recovering finer gold particles.

"In the past twenty years, some new machines that can very effectively concentrate gold by gravity have been developed," the late Professor Laplante stated. "Centrifuge units and jigs produce small masses of high-grade gravity gold concentrate."

Traditionally, these concentrates have been further physically concentrated by a shaking table in the gold room, before smelting and pouring into bullion bars. For the last 10 years commercial devices have been increasingly preferred for processing gravity concentrates via a hydrometallurgy route. These systems utilise intensive cyanidation, with gold recoveries exceeding 95%, a massive improvement over the 50 – 60% expected from a gold room. Gold from the resulting gold solution can then be directly recovered by electrowinning followed by a furnace to pour gold from the gold cathode. As gravity gold concentrates are an exceptionally small fraction of the plant feed, high cyanide concentrations utilise only a small amount of cyanide for treatment. Security is also improved by eliminating manual handling of gold concentrates, and intensive cyanidation has environmental benefits and low operating costs.

Sadiola Gold Mine – Mali

AngloGold Ashanti has interests in three mines in Mali, amongst them Sadiola (38%), held in partnership with the government of Mali, Canadian listed company IAMGOLD and the International Finance Corporation. Sadiola is situated 77km south of the regional capital of Kayes and has produced about 4Moz of gold since its establishment in 1996.



Geology: The Sadiola deposit occurs within an inlier of greenschist facies metamorphosed Birimian rocks known as the Kenieba Window. The specific rocks that host the mineralisation are marbles and greywackes which have been intensely weathered to a maximum depth of 200m. A series of north-south trending faults occurs which feeds the Sadiola mineralisation. As a result of an east-west regional compression event, deformation occurs along a north-south striking marble-greywacke contact, increasing the porosity of this zone. North-east striking structures, which intersect the north-south contact, have introduced mineralisation, mainly with the marble where the porosity was greatest.

The Sadiola Hill deposit generally consists of two zones: an upper oxidised cap and an underlying sulphide zone. From 1996 until 2002, shallow, Saprolite oxide ore was the primary ore source. Since 2002, the deeper Saprolitic sulphide ore has been mined and will progressively replace the depleting oxide reserves.

Mining and processing: Mining takes place in five open pits and the ore mined is treated and processed in a 4.5 Mtpa carbon-in-pulp (CIP) gold plant.

Gravity concentration at Sadiola.

Gravity concentration technology was never installed at Sadiola initially. With the introduction of the high grade sulphide ores, plant recoveries were less than satisfactory. The management of Sadiola decided to investigate the utilisation of gravity concentration for plant optimisation to improve the recovery of sulphide ores.

LABORATORY TESTWORK

In mid 2006 Steve McAlister of Falcon Concentrators was asked to visit the Sadiola site. Subsequent to this visit, after consultation with site personnel, a test program was initiated on both the Oxide and the Sulphide type ores. The purpose of the test work was to determine the potential recovery benefits of a gravity installation for batch and / or continuous concentrators. The test work involved both gravity and leaching tests.

In order to measure the potential benefit of a gravity installation, it was decided to simulate the circuits of interest in a laboratory environment with a view to compare the final gold recovery of the different potential circuits.

- The first circuit to be examined was the baseline existing circuit. A sample of feed for both Oxide and Sulphide type ore, ground to existing plant grind size, and leached under existing plant conditions gave a recovery base line for comparison with new circuits.

- The second circuit examined was one in which a batch concentrator was placed in the circulating load of the grinding circuit. In this case, a feed sample is run through a laboratory concentrator, creating a concentrate and a tailing. The concentrate is panned to produce a final high-grade concentrate and a concentrate tail. The initial tailing and the concentrate tail are combined and leached under existing plant conditions. In this way the removal of Gravity Recoverable Gold from the leach feed using a batch machine and the effect of this on downstream leach performance is simulated.

- The final circuit configuration examined was one that utilises two types of gravity concentrators. In this case, the feed sample is run through a laboratory concentrator, creating a concentrate and a tailing. The tailing is leached under existing plant conditions, in this way simulating the removal of Gravity Recoverable Gold from the leach feed using a batch concentrator in the circulating load of the grinding circuit. In addition one could simulate the removal of Gravity Recoverable Gold Plus by continuous concentrators in the cyclone overflow. One can then measure the combined effect of the gravity installations on downstream leach performance and overall recovery.

GRG tests

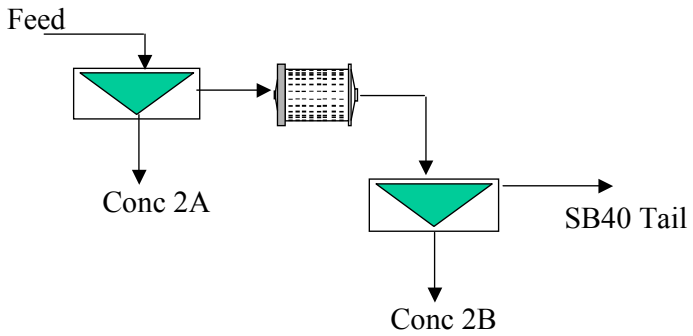
To assist in the modelling accuracy of the tests, a standard Laplante style GRG test was performed on each ore type. When modelling the circuit, this theoretical limiting GRG number and model the inherent inefficiencies in the circuit to arrive at the actual expected plant recovery.

"GRG" or Gravity Recoverable Gold will identify completely free and liberated particles of gold that occur in a recoverable size range and thus will report to a batch type centrifugal concentrator. This type of gold can be concentrated into a very small mass suitable for the batch type concentrator's limited concentrate yield. A cyclone is an excellent rougher for GRG.

"GRG+" or Gravity Recoverable Gold Plus" denotes the gold available when utilizing a continuous centrifugal concentrator that has a higher concentrate yield capacity. In these machines, both free gold and middling gold will report to the concentrate. Middling gold is defined as gold associated with other heavies such as sulphides. In most cases, a much higher recovery can be achieved if we target both types of gold (GRG and GRG+).

Oxide Sample

A 20 kg sample was taken from the initial sample and used for the GRG test on the Oxide ore. The size distribution of the sample as received was a P_{80} of 268 microns. The material was processed in two passes as shown below.



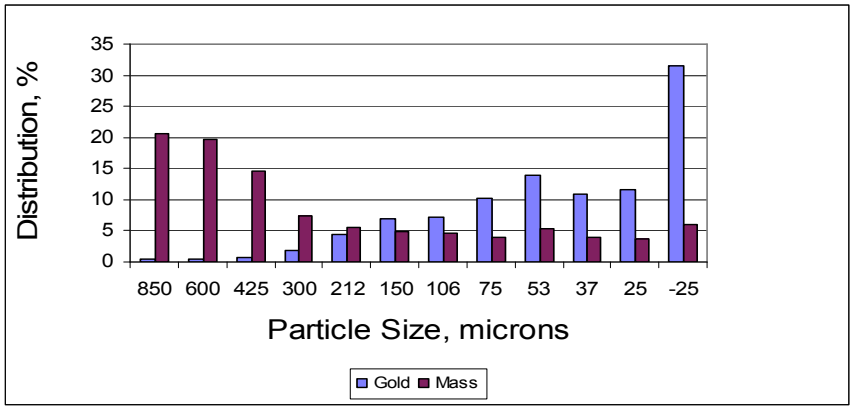
Normally, a GRG test consists of three passes through a laboratory concentrator. The first pass is done on the sample as received. The second pass is done after an intermediate grind while the third pass is done after a final grind. Each stage of grinding liberates additional gold. In this case, the material as received was very fine and two grinds were not feasible for reduction to final grind size. In this case, only one grind was used and only two passes through the laboratory machine. To simply pass the final grind material through the laboratory machine twice in order to achieve the normal three passes has been proven to overestimate the amount of GRG in the ore. For the purposes of the exercise for Sadiola, it was decided to be very conservative and stop at two passes. While this under represented the amount of GRG, the danger of overestimation of performance was eliminated.

Recovery data on the GRG test can be summarised in the following chart.

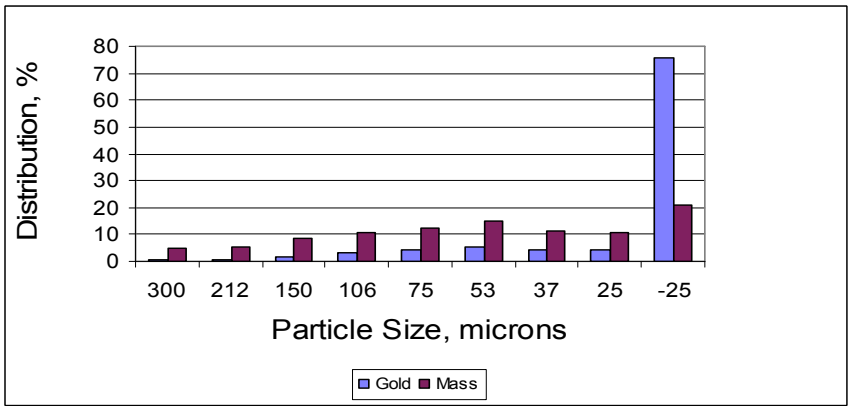
Products	Weight		Assay	Distribution, %
	g	%	Au, g/t	Au
Concentrate 2A	98.1	0.5	195.19	28.4
Concentrate 2B	232.0	1.2	87.64	30.2
SB40 Concentrate 2A+2B	**330.0**	**1.7**	**119.60**	**58.6**
SB40 Tails	19,670.0	98.3	1.42	41.4
Calculated Head	**20,000.0**	**100.0**	**3.37**	**100.0**
Measured Head				

Chart 1. Oxide GRG results.

From this test we can see that the total GRG is 58.6%. However, as noted earlier, this is a very conservative number given the use of only two passes. Each concentrate was analyzed by size fraction for gold content.



Graph 1. PSD and Au deportment in 1st pass – Oxide sample

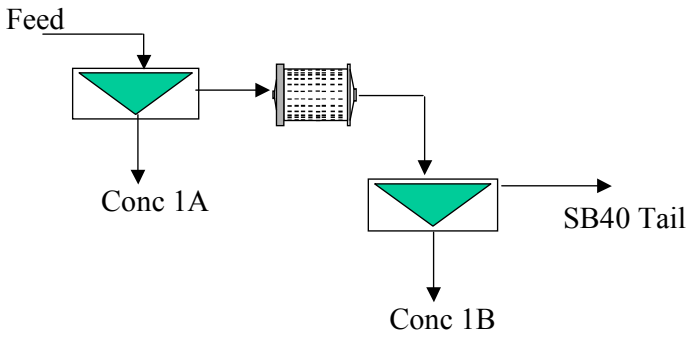


Graph 2. PSD and Au deportment in 2nd pass – Oxide sample

When looking at the size distributions we note that there is a great deal of fine gold in the concentrate. In both the first pass and the second pass there was a very high proportion of extremely fine minus 25 micron gold. High G force is necessary to capture this fine gold. The laboratory concentrator was operated at 150 G.

Sulphide Sample

A 20 kg sample was taken from the initial sample and used for the GRG test on the Sulphide ore. The size distribution of the sample as received was a P_{80} of 232 microns. The material was processed in two passes as shown below.



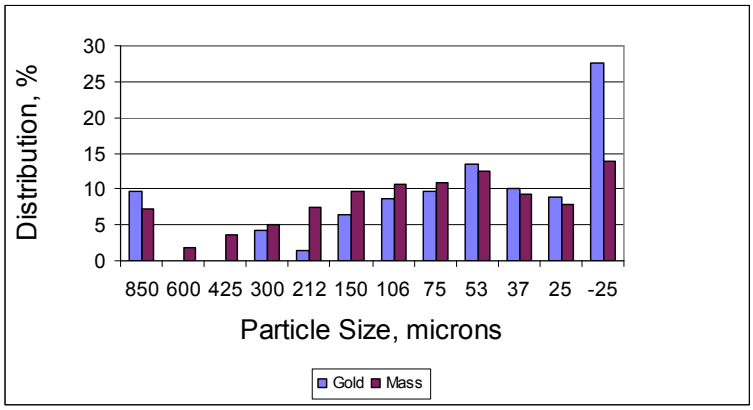
Recovery data on the GRG test can be summarized in the following chart.

Products	Weight		Assay	Distribution, %
	g	%	Au, g/t	Au
Concentrate 1A	170.2	0.9	137.66	25.1
Concentrate 1B	244.4	1.2	109.64	28.7
SB40 Concentrate 1A+1B	**414.6**	**2.1**	**121.14**	**53.8**
SB40 Tails	19,585.4	97.9	2.20	46.2
Calculated Head	**20,000.0**	**100.0**	**4.67**	**100.0**
Measured Head				

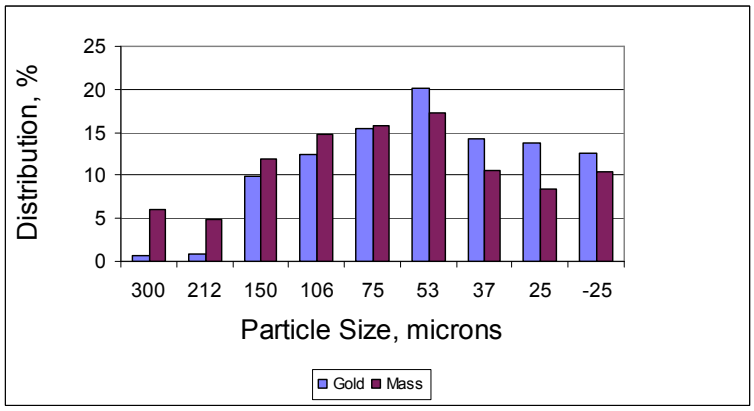
Chart 2. Sulphide GRG results.

From this test we can see that the total GRG is 53.8%. However, as noted earlier, this is a very conservative number given the use of only two passes.

Each concentrate was analysed by size fraction for gold content.



Graph 3. PSD and Au deportment in 1st pass – Sulphide sample



Graph 4. PSD and Au deportment in 2nd pass – Sulphide sample

When looking at the size distributions we note that there is a great deal of fine gold in the concentrate. Specifically, we can see that in the first pass there was a very high proportion of extremely fine minus 25-micron gold. Much of this gold was already liberated in the sample as received. We see in the second pass that there is a lesser distribution of fine gold, indicating the high level of efficiency of the SB40 concentrator in the first pass. High g-force is necessary to capture this fine gold. The SB40 concentrator was operated at 150 g.

The gold in the Sulphide sample has a coarser distribution than the gold in the Oxide sample.

Oxide Ore – Gravity and Leach Tests

Three tests were performed. The first test was used as a baseline to simulate the existing circuit without any gravity concentration. The second test was used to simulate the use of a batch type centrifugal concentrator while the third test was used to simulate the use of both a batch type and a continuous type concentrator.

Oxide Ore – Leach Circuit Baseline Simulation

Two kg of Oxide sample material at a P_{80} of 68 microns was used to simulate the current plant leach conditions. The results are summarized below.

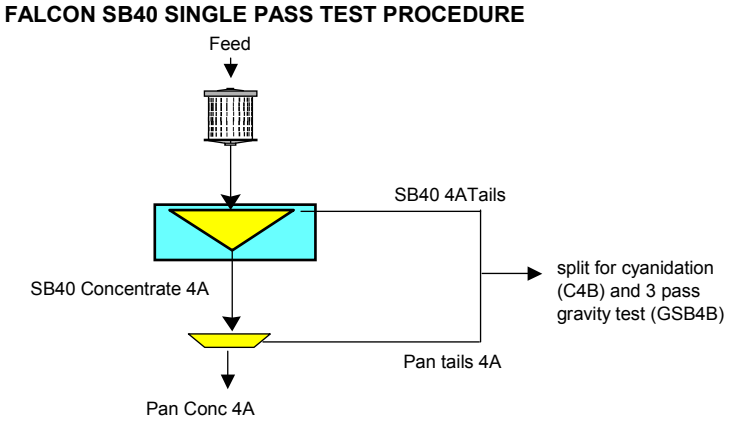
CYANIDATION RESULTS

Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
22	**92.5**	**1.75**	**1.87**
Residue	7.5		
Total	100.0		

Note that the overall leach recovery was 92.5% with a cyanide consumption of 1.75 kg/t.

Oxide Ore – Batch concentrator and Leach Circuit Simulation

A 20 kg sample of Oxide material was split to utilise in this test. The 20 kg of material was first ground to simulate the Sadiola grind product, and then passed through a laboratory concentrator. The test procedure is shown in the following diagram. Some of the tails were utilised for cyanidation in this test whilst a cut was also taken for the next test.



The following chart summarizes the gravity concentration step. The P_{80} of the sample after grinding was 68 microns.

Products	Weight		Assay	Distribution
	(g)	(%)	Au (g/t)	Au (%)
Pan Concentrate 4A	3.65	0.02	2769.0	12.8
GSB 4A Pan Tails +Gravity Tails	19,900	100.0	3.46	87.2
Total	**19,903**	**100.0**	**3.97**	100.0

The test results indicate that 12.8% of the gold was removed by the laboratory concentrator into a very high-grade pan concentrate.

A cut of the gravity tails plus the pan tails was taken for leaching. The results are shown below.

CYANIDATION RESULTS

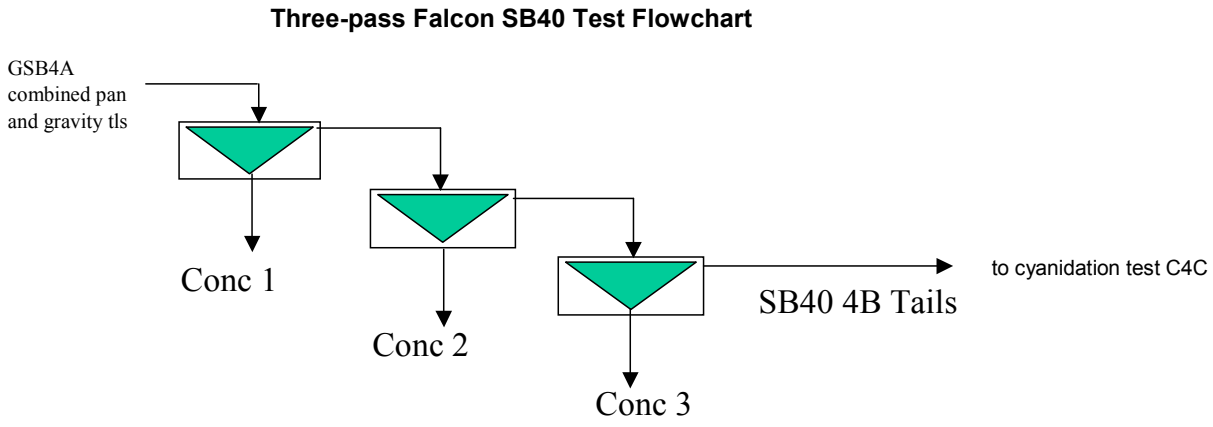
Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
22	**96.4**	**0.74**	**1.32**
Residue	3.6		
Total	100.0		

The results indicate that 96.4% of the gold was leached into solution. The cyanide consumption was 0.74 kg/t. Note that this is 3.9% higher than the leach result without gravity concentration. The cyanide consumption in this test is also only 43% of that used in the baseline test.

Oxide Ore – Batch and Continuous concentrator with Leach Circuit Simulation

A cut of the gravity tails from the last test was utilised for feed in this test. The material was first passed through a laboratory concentrator for three consecutive passes. This high mass yield test simulates the action of a Continuous concentrator installed in the cyclone overflow. The tails from this gravity test were then leached.

The test procedure is shown in the following diagram.



The following chart summarises the three-pass gravity concentration step. The P_{80} of the sample after grinding was 68 microns.

Products	Weight		Assay	Distribution, %
	g	%	Au, g/t	Au
SB40 Concentrate 1	56.4	3.8	16.00	15.5
SB40 Concentrate 2	65.1	4.3	5.80	6.5
SB40 Concentrate 1+2	**121.5**	**8.1**	**10.54**	**22.0**
SB40 Concentrate 3	64.2	4.3	3.80	4.2
Total SB40 Concentrate	**185.7**	**12.4**	**8.21**	**26.1**
SB40 4B Tails	1,314.3	87.6	3.28	73.9
Calculated Head	**1,500.0**	**100.0**	**3.89**	**100.0**

The test results indicate that 26.1% of the gold was removed by the batch concentrator in a 12.4% mass yield.

It should also be noted that these concentrate weights are lower than usual which would negatively affect recovery. It is likely that the unusually fine ore would have benefited from a lower fluidization pressure. It is not possible to optimize these types of tests, but it is possible to optimize in a plant environment.

A cut of the gravity tails was taken for leaching. The results are shown below.

CYANIDATION RESULTS

Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
19	**99.4**	**0.19**	**1.34**
Residue	0.6		
Total	100.0		

The results indicate that 99.4% of the gold was leached into solution. The cyanide consumption was 0.19 kg/t. Note that this is 6.9% higher than the leach result without gravity concentration and 3% higher than the leach result with only a batch concentrator. The cyanide consumption in this test is also only 11% of that used in the baseline test and only 26% of that used in the batch simulation test.

Sulphide Ore-Gravity and Leach Tests

Three tests were performed. The first test was used as a baseline to simulate the existing circuit without any gravity concentration. The second test was used to simulate the use of a batch type centrifugal concentrator while the third test was used to simulate the use of both a batch type and a Continuous type concentrator.

Sulphide Ore – Leach Circuit Baseline Simulation

Two kg of Sulphide sample material at a P_{80} of 65 microns was used to simulate the current plant leach conditions. The results are summarized below.

CYANIDATION RESULTS

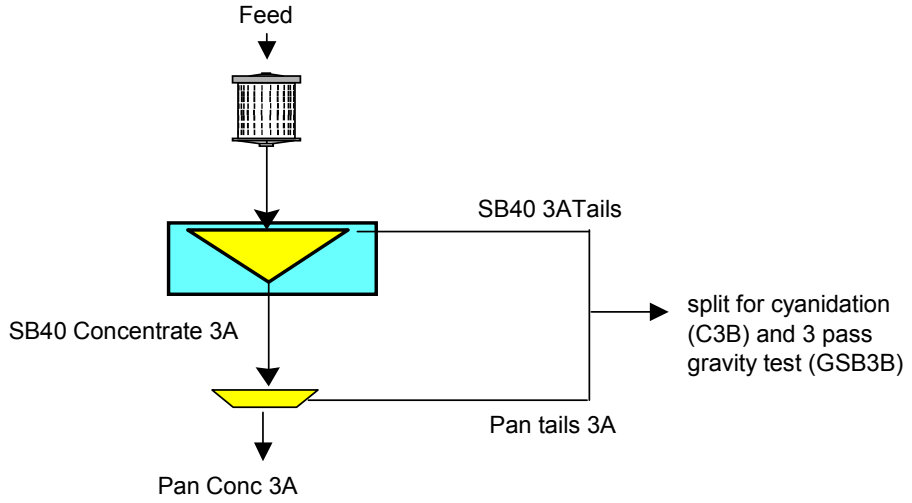
Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
22	**73.0**	**0.71**	**1.43**
Residue	27.0		
Total	100.0		

Note that the overall leach recovery was 73% with a cyanide consumption of 0.71 kg/t.

Sulphide Ore – Batch concentrator and Leach Circuit Simulation

A 20 kg sample of Sulphide material was split to utilise in this test. The 20 kg of material was first ground to simulate the Sadiola grind product, and then passed through a laboratory concentrator. The test procedure is shown in the following diagram. Note that some of the tails were utilized for cyanidation in this test while a cut was also taken for the next test.

FALCON SB40 SINGLE PASS TEST PROCEDURE



The following chart summarizes the gravity concentration step. The $P_{80}$of the sample after grinding was 65 microns.

Products	Weight		Assay	Distribution
	(g)	(%)	Au (g/t)	Au (%)
Pan Concentrate 3A	4.13	0.02	2348.8	10.7
GSB 3A Pan Tails +Gravity Tails	19,739	100.0	4.09	89.3
Total	**19,743**	**100.0**	**4.58**	100.0

The test results indicate that 10.7% of the gold was removed by the laboratory concentrator into a very high-grade pan concentrate.

A cut of the gravity tails plus the pan tails was taken for leaching. The results are shown below.

CYANIDATION RESULTS

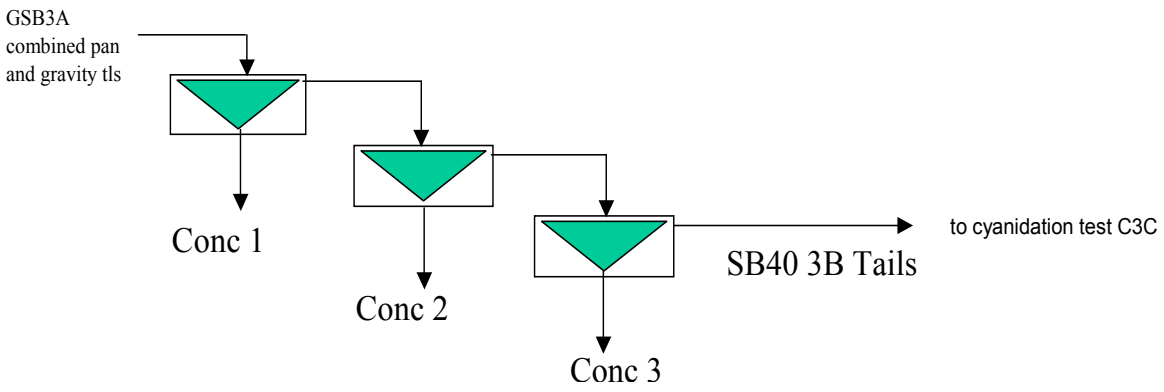
Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
22	**74.6**	**1.20**	**0.99**
Residue	25.4		
Total	100.0		

The results indicate that 74.6% of the gold was leached into solution. The cyanide consumption was 1.20 kg/t. Note that this is 1.6% higher than the leach result without gravity concentration. The cyanide consumption in this test was 1.7 times that used in the baseline test. There is logically little reason for this increase in cyanide consumption when compared to the baseline.

Sulphide Ore – Batch and continuous concentrators and Leach Circuit Simulation

A cut of the gravity tails from the test above was utilised as feed in this test. The material was first passed through a laboratory concentrator for three consecutive passes. This high mass yield test simulates the action of a Continuous type concentrator installed in the cyclone overflow. The tails from this gravity test were then leached. The test procedure is shown in the following diagram.

Three-pass Falcon SB40 Test Flowchart



The following chart summarizes the three-pass gravity concentration step. The P_{80} of the sample after grinding was 65 microns.

Products	Weight		Assay	Distribution, %
	g	%	Au, g/t	Au
SB40 Concentrate 1	86.8	5.8	31.60	43.4
SB40 Concentrate 2	65.8	4.4	14.20	14.8
SB40 Concentrate 1+2	**152.5**	**10.2**	**24.10**	**58.2**
SB40 Concentrate 3	70.3	4.7	7.00	7.8
Total SB40 Concentrate	**222.8**	**14.9**	**18.70**	**65.9**
SB40 3B Tails	1,275.2	85.1	1.69	34.1
Calculated Head	**1,498.0**	**100.0**	**4.22**	**100.0**

The test results indicate that 65.9% of the gold was removed by the concentrator in a 14.9% mass yield.

A cut of the gravity tails was taken for leaching. The results are shown below.

CYANIDATION RESULTS

Time	Distribution	Reagent Consumption	
	Au	NaCN	$Ca(OH)_2$
(hours)	(%)	(kg/t)	(kg/t)
19	**87.8**	**0.70**	**0.95**
Residue	12.2		
Total	100.0		

The results indicate that 87.8% of the gold was leached into solution. The cyanide consumption was 0.70 kg/t. Note that this is 14.8% higher than the leach result without gravity concentration and 13.2% higher than the leach result with only a batch concentrator. The cyanide consumption in this test is essentially the same as that used in the baseline test and much less than that used in the batch simulation test (although this last result has already been noted as illogical and therefore suspect).

Recovery Benefit Summary

Three different circuit configurations were tested for each ore and the results are summarised below.

Potential Circuit Leach Recoveries	% Recovery in Leach			
	Oxide	**% increase**	Sulphide	**% increase**
Baseline - No Gravity	92.5		73	
Falcon SB plus Leach	96.4	**3.9%**	74.6	**1.6%**
Falcon SB and Falcon C plus Leach	99.4	**6.9%**	87.8	**14.8%**

Oxide and Sulphide – Batch gravity concentration and Leach

The Oxide material exhibited a **3.9% recovery benefit** when comparing the leach of the gravity tails and the leach of the whole ore. For the Sulphide material, the same comparison yielded a **1.6% recovery benefit**.

It was recommended that the gravity concentrate be treated as well, and given its extremely small mass, it as expected that it would be relatively easy to attain extremely high recoveries in an intensive leach.

Oxide and Sulphide – Batch and Continuous gravity concentration and Leach

The Oxide material exhibited a **6.9% recovery benefit** when comparing the leach of the concentration tails and the leach of the whole ore. For the Sulphide material, the same comparison yielded a **14.8% recovery benefit**.

Conclusion of laboratory testwork

It was the conclusion of the testwork that both types of ore at Semos-Sadiola exhibited strong amenability to gravity recovery, which, if approached in the correct fashion, could result in significantly increased recoveries.

Based on this, the management of Sadiola decided to initially install a batch type centrifugal concentrator into the recirculating load of the milling circuit. In addition, a decision was made to withhold high grade sulphide feed prior to the commissioning of the gravity concentrator in December 2007.

PLANT INSTALLATION AT SADIOLA

Sadiola decided to take an aggressive approach to gravity recovery by designing a circuit that would maximize recovery by gravity while fitting the existing infrastructure at a minimum cost. After careful consideration, it was decided to install a protection screen ahead of a Falcon Model SB5200SE Falcon Concentrator, with the concentrate to report to a Gekko Systems Model 3000 ILR.

The plant was successfully commissioned in December 2007, and the following pertinent parameters have been established;

- Recoveries prior to gravity : 76 - 78%
- Recovery after gravity : 80%
- Gold recovery in gravity section : 12%
- Leach feed grade : 3.54 g/t
- Concentrator grade on average : 2 600 g/t
- Feed to ILR (normally) : 3 – 5 ton batches
  - NaCN : 15000 – 20000ppm
  - Peroxide addition for oxygen : 50%
  - pH : 11.5
- ILR recovery : 98.7 %
- Ave mass of gold recovered : 150 kg per month

SUMMARY

The gravity section has consistently achieved a recovery on average of 5 kg gold per day at the Sadiola mine in Mali since being installed in December 2007.

When one compares the results of the laboratory tests, the recovery predictions and the results achieved on the plant, it is clear that well conducted and accurate laboratory testwork can be successfully employed for the prediction of actual plant operation.

The actual results also fit within the Laplante hypothesis. The late Dr Laplante suggested that for every 10% of gold recovered by gravity, there was a corresponding 0.1% to 1% additional overall plant recovery. The results at Sadiola consistently show as much as an overall 4% gain in plant recovery, 0.33% for every 1% of gravity gold recovery.

ACKNOWLEDGEMENTS

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