A Standardized Test to Determine Gravity Recoverable Gold

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ABSTRACT

A test to determine the amount of gravity recoverable gold (GRG) in an ore is described. Typical GRG results are given; possible uses and typical diagnostics are prescntcd.

Of the 38 samples tested, the lowest GRG content was found to be 25% (most below 25 μm, or 600 mesh), and the highest 94% (most above 300 pm, or 50 mesh). The average GRG content was 63%, with a standard deviation of 19%.

The test has been applied to greenfield project and retrofit applications, to determine the suitability of gravity recovery. For existing circuits, it has been coupled with a model of gravity recovery for optimization studies. Actual diagnostics and uses of the test are dicussed.

INTRODUCTION

Using gravity to supplement either flotation or cyanidation is a well established practice in the gold industry. Gravity differs from other recovery methods in that most of the gold recovered by gravity would be recovered by the circuit downstream, be it flotation or cyanidation, should gravity be by-passed. The economic justification of gravity is therefore based on small margins (for example, a net smelter return of gravity gold of 99%, as opposed to 94% for flotation). It was easily demonstrated when either flotation or cyanidation were relatively inefficient processes, and labour costs low (as gravity can be labour intensive). Over the past thirty years, however, the introduction of better flotation machines (flash, column, high capacity), more effective collectors, and better control systems has increased flotation's metallurgical performance, thereby decreasing the incentive for gravity recovery. Cyanidation technology has undergone similar changes, with the advent of activated carbon, oxygen and lead nitrate addition, and improved impeller design.

Today, gravity can remain an attractive option only inasmuch as it can be implemented with very low capital and operating costs. This has resulted in a relative shift away from gold gravity recovery (except for alluvial deposits), in the seventies and eighties. For example, as of the early nineties, gold gravity recovery has disappeared from the typical South African flow sheet. The advent of the Knelson Concentrator, at the beginning of the eighties, foreshadowed a resurgence of gravity recovery, as gold's grinding and classification behaviour (Banisi, Laplante and Marois, 1991) makes it possible to achieve adequate gold recoveries with very simple, Knelson based, gravity circuits (Laplante et al., 1994).

Consider for example the Hemlo recovery circuit (Honan, 1996; Laplante, Vincent and Luinstra, 1996), consisting of a single 61 cm x 122 cm (2' x 4') screen, an automated 76 cm (30") Knelson feeding a Gemeni table, to produce a 70-80% Au concentrate which accounts for approximately one fourth of the gold production (about 3 million grams per year). The low capital and operating costs make it possible to justify the gravity circuit on the basis of savings in other operating costs (e.g. fewer carbon stripping cycles). Any improvements in recovery, which are at Hemlo difficult to measure, would be additional benefits. Such a circuit is rapidly becoming a standard in Canadian and Australian operations.

The justification for installing a gravity circuit must be first based on an estimate of how much gold it will recover (irrespective of what the potential benefits are). This is a function of the nature of the gravity circuit to be installed; however, Knelson circuits, by their very simplicity and efficiency, limit the options. This leaves the amenability of the ore to gravity recovery as the single most important factor in predicting gravity recovery. Various approaches can be used to characterize this response (Woodcock, 1994). The present work sought a route which would fulfil the following criteria:

1. The test should be statistically reliable. This calls for a minimum mass to be treated which varies from ore to ore (depending on gold content and particle size), but has been found to be around 40 to 70 kg for most.

2. The test should rely on technologically up-to-date separation equipment. Centrifuge units have been shown to outperform devices that rely on the earth's natural gravity field. Since these units (especially the Knelson for gold) are now commonly used at plant scale, they should also be used at lab scale to characterize recoverability.

3. The test should indicate not only how much gravity recoverable gold (GRG) the ore contains, but its size distribution and the grind at which it is liberated. This should preferably be available with a single test, to minimize the mass of sample required (as sample mass is often in short supply, especially for greenfield applications).

4. The test should be free of the usual pitfalls of gravity testing, such as gold traps, using samples from circulating loads non representative of steady-state operation. or producing a concentrate that cannot be upgraded to smelting grade (i.e. recovering gold that is not GRG).

5. The test has to be inexpensive, as gravity will not be the main recovery method, and its use justified only on the basis of economy of effort, inclusive of the planning stage.

METHODOLOGY

The test is based on the treatment of a sample mass of typically 50 kg with a laboratory Knelson Concentrator (LKC). Three stages are used, the first on the sample crushed and rod milled to 100% -850 µm, and the next two on part of the tails of the previous stage, ground to achieve further gold liberation. Stage two is performed on typically 24 kg ground at 45-55% -75 pm, and stage three on 18 to 21 kg ground at 75-80% -75 pm.

The Knelson tests are performed at increasingly lower feed rates and fluidization water pressures to match the finer feed, typically from 1000 g/min and 25 kPa for stage 1 to 400 g/min and 12 kPa for stage 3. These correspond to optimal settings as determined by extensive test work with both gold ores and synthetic feeds, but must be adjusted for gangue density (Laplante, Shu and Marois, 1996; Laplante et al., 1995a). Because the test is optimized, it yields the maximum amount of GRG; actual plant recoveries will be lower. because of limitations in equipment efficiency and of the usual approach of processing only a fraction of the circulating load. Linking projected plant recovery to the results of the GRG test will be briefly discussed later.

For each stage, all of the concentrate and 600 g of tails are screened from 25 to 600 μm (the tail sample is wet screened first). The tail fractions above 105 μm are further pulverized prior to assaying. All of the concentrate screen fractions and up to one assayton of tails are fire-assayed.

The test was used on more than 30 ore types, ranging from completely oxidized to complex sulphides. Some ores were tested twice with the regular procedure to assess natural variability. Additional work included performing either a single or all three LKC stages at final grind, to check the validity of the basic approach and explore possible simplifications. These additional tests are discussed at length in Woodcock and Laplante (1993); they show that the progressive grinding (as opposed to testing only at final grind) is necessary to obtain the correct size distribution of GRG, as well as a measure of progressive liberation. Testing only at final grind normally underestimates the GRG content, because of overgrinding. Testing feed masses below IO kg can result in a slight overestimate of GRG content for ores with a low sulphide content.

BASIC RESPONSE

Stage recoveries are based on the concentrate and tail assays of each stage. However, overall recovery is based on the assays of the three concentrates and the tails of the third stage, whose assays are more reliable than those of the first two, which still contain some of the GRG. Results are normally presented as size-by-size recoveries for each stage (Table I), and overall recovery (Table 2). However, a graphic representation is more informative. and will be used in this paper.

Figure I shows the three basic responses, ranging from very poor (A) to the exceptionally amenable (C). Most free-milling gold ores exhibit an intermediate response (B). These responses are presented as the cumulative percent GRG.retained (100% = total gold in the ore) for all three liberation stages. Taking the intermediate response, it can be detailed into cumulative recoveries for one, two and three stages, as shown in Figure 2. An alternative presentation is to show cumulative recovery as a function of grind size (Figure 3); this presentation is particularly useful if the data are to be used on a grind size different from that of the final product --e.g. for complex grinding circuits, such as Hemlo's (Banisi, Laplante and Marois, 1991).

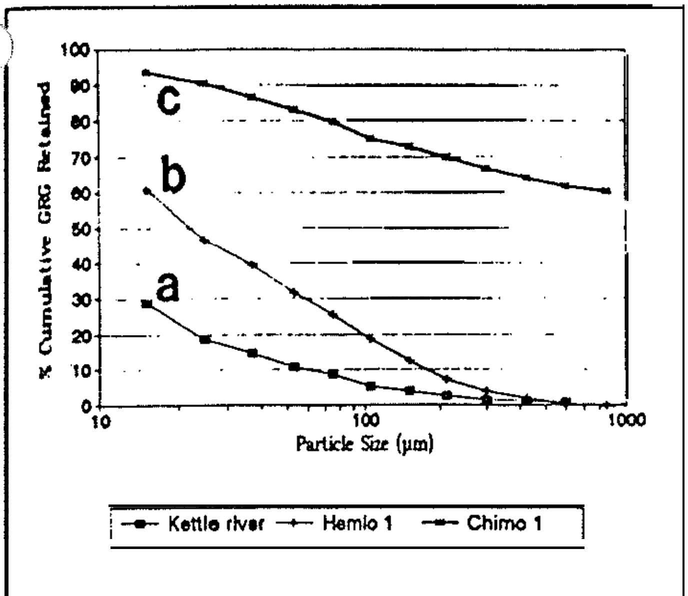
Table 1. Metallurgical balance of the first stage

Hemlo Second Sample. First Test. 100% -850 µm (20 mesh)
4.0 pm 990 g/t
ile (51\SEP94\2HEMLO 1.WQ1)

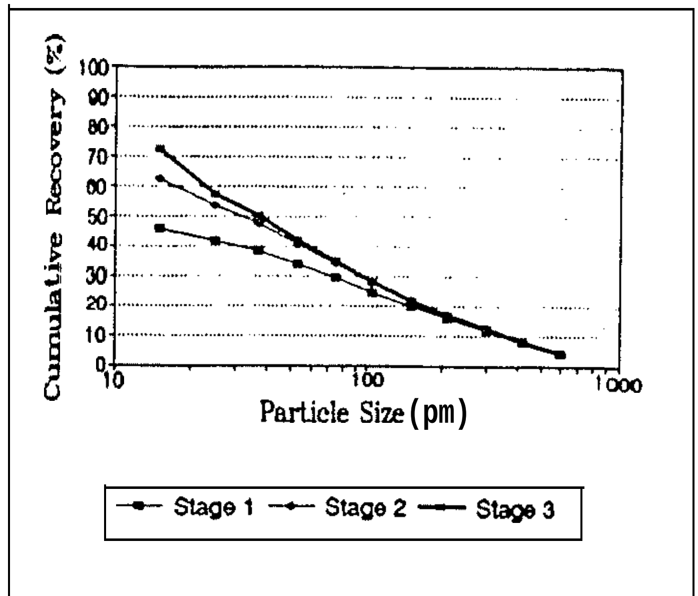
Size µm	CONCENTRATE Weight (g)	% %Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% %Weight	Grade (g/t)	Rec. (%)	FEE Weight (g)	% %Weight	Grade (g/t)	Dist'n (%)
600	6.61	5.52	3503	55.2	1708	3.43	11.0	44.8	1714	3.44	24.5	7.7
420	9.50	7.93	1943	54.2	2164	4.35	7.2	45.8	2173	4.36	15.7	6.2
300	17.46	14.57	1355	50.8	3548	7.13	6.5	49.4	3566	7.15	13.1	8.6
210	19.43	16.21	1050	43.7	4527	9.10	5.8	56.3	4547	9.12	10.3	8.6
150	25.12	20.96	915	42.3	6542	13.15	4.8	57.7	6567	13.17	8.3	10.0
105	17.70	14.77	1320	45.8	6427	12.92	4.3	542	6445	12.93	7.9	9.3
75	11.40	9.51	2398	55.0	6219	12.50	3.6	45.0	8231	1250	6.0	9.1
53	5.83	4.87	4127	82.7	3871	7.78	3.7	37.3	3876	7.77	9.9	7.0
37	3.66	3.05	6708	65.0	3143	6.32	4.2	35.0	3146	8.31	12.0	6.9
25	1.61	1.34	11229	80.2	2175	4.37	5.5	39.8	2177	4.37	13.8	5.5
-25	1.51	1.26	13744	18.1	9417	18.93	10.0	81.9	9418	18.89	12.2	21.1
Total	119.83	100.00	2060	45.2	49740	100.00	6.0	54.8	49860	100.00	10.9	100.0

Table 2. Overall results, second Hemlo sample

Size (µm)	First Stage: 100% -850 µm Stage Recov'y	Dist'n	Recov'y g/t	Second Stage: 57.5% -75 µm Stage Recov'y	Dist'n	Recov'y g/t	Third Stage: 80.3% -75 µm Stage Recov'y	Dist'n	Recov'y g/t	Losses g/t	Total Recov'y g/t	Total Recov'y %
600	552	7.7	0.48	0.0	0.0	0.00					0.464	4.3
420	54.2	6.2	037	9.6	0.6	0.00					0.374	3.5
300	50.6	8.6	0.47	49.0	1.3	0.04					0.512	4.7
210	43.7	8.6	0.4,	49.8	2.4	0.07	0.0	0.0	0.00	0.00	0.478	4.4
150	42.3	10.0	0.46	16.6	8.4	0.09	56.0	0.7	0.02	0.01	0.567	5.3
105	458	9.3	0.47	25.8	10.0	0.15	20.7	3.4	0.03	0.1 I	0.846	8.1
75	55.0	8.1	0.55	34.9	8.3	0.19	14.5	a.2	0.05	0.28	0.784	7.:1
53	82.7	7.0	0.48	46.6	7.3	0.20	21.2	7.8	0.08	0.24	0.744	6.9
37	85.0	8.9	0.49	58.1	7.9	0.26	38.8	8.3	0.12	0.2,	0.873	8.1
25	60.2	5.5	0.38	55.7	8.8	'0.28	46.8	7.8	0.14	0.16	0.783	7.3
15	18.1	21.1	0.42	21.9	44.1	0.58	24.4	84.2	0.83	1.95	I.604	14.9
Total	45.9	100.0	4.95	31.3	100.0	1.83	26.2	100.0	1.05	2.96	7.830	72.54
O/A	45.9			16.95			9.7					
Yield	0.0024			0.00584			0.00776					
Grade	10.94 g/t			5.81 g/t			4.05 g/t					
Calc:	10.79 g/t											



'igure 1. Three basic responses to the GRG 'test



igure 2. Cumulative recovery of the thre stages, second Hemlo sample

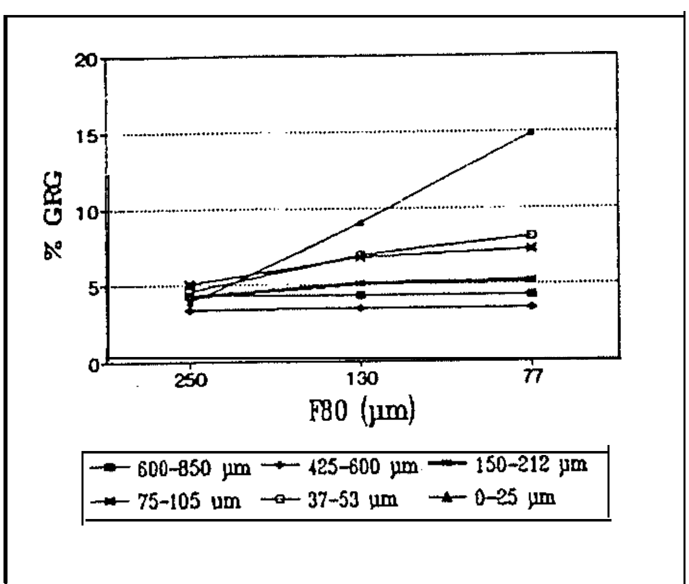
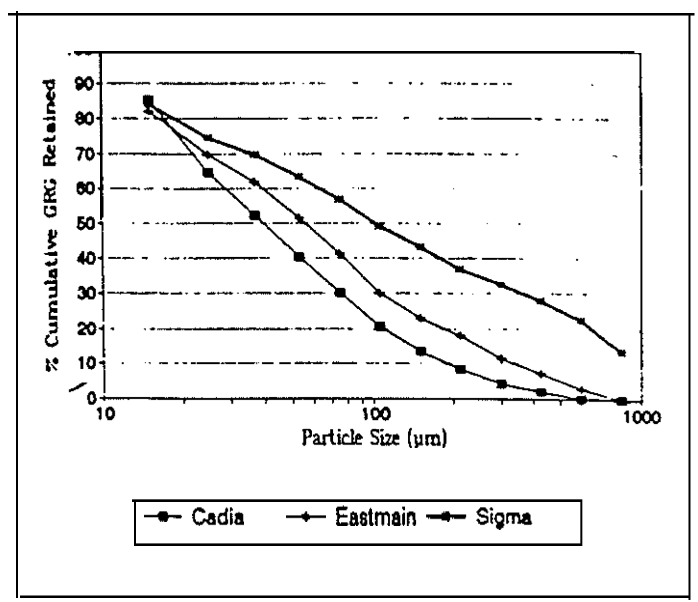


Figure 3. %GRG in various size classes as a function of grind (100% = total gold in ore)



igure 4. GRG Size distribution of three samples with similar GRG content

Even at 'constant' response, the size distribution of the GRG and the grind size at which gold is liberated vary significantly. For example, consider Figure 4, which shows the size distribution of GRG responses in the 82 to 86% GRG range. The first is extremely tine. and would require a recovery unit capable of very fine gold recovery (e.g. flash flotation). The second, Eastmain, has an intermediate response, and has responded well to Knelson-based gravity recovery. The third ore would be easily recovered by gravity, and the very coarse GRG identifies a potential security risk. Similar variations have been observed for poor and intermediate responses. There is, however, a general correlation between the size distribution of gold (represented by its F,,) and the amount of GRG, as shown in Figure 5. Notice that highly weathered ores (circled points) slightly outperform the average, whereas base metal and massive sulphide ores (identified with diamonds) clearly perform more poorly. Overall. the thirty-seven tests yielded an average GRG content of 62.5±19.3%, at an average final grind of 77% -75 µm. The lowest GRG content was 25% (most of which below 25 pm). the highest 94% (most of which above 300 µm). Despite the correlation between gold's F_{80} (F_{80}^{Au}) and the total GRG content, prediction of the latter using the former would be inaccurate (standard deviation: 1 1%):

$$\%GRG = -17.9 + 17\pm2 \ln (F_{80}^{Au})$$
$$(\rho^2 = 0.70)$$

The total amount of GRG is also correlated to that of the first stage, GRG,. as shown in Figure 6. The correlation can be used to predict the results of the test from those of the first stage, but not very accurately (standard deviation: 10%):

$$\%GRG = 33.6 + 0.91\pm0.09\ GRG,$$
$$(\rho^2 = 0.75)$$

However, Figure 6 shows that there is more uncertainty at low GRG, values: recoveries of less than 20% for stage 1 can still result in overall GRG contents of about 50%, whereas stage 1 recoveries in excess of 40% almost always result in overall GRG contents in excess of 75%.

The reproducibility of the test is discussed at length in Laplante and Doucet (1996). Table 3 shows the reproducibility of some tests. In the case of Cadia and Troilus, samples were extracted from different zones, and would not be expected to yield similar results. For MSV, Hemlo and Chimo, the first test was performed with suboptimal samples (either too small or made of a single increment), but from the same ore. Results show a scatter of 5 to 10%, which would have no impact on the diagnostic, and limited impact on the predicted gravity recovery. Finally, the Snip and Aur samples were extracted according to the prescribed methodology, one year part for Aur and three years apart for Snip. Results are remarkably similar. Generally, test results will be highly reproducible when no gold is coarser than 850 µm (20 mesh). In the presence of +850 µm, the size of the initial sample to be crushed to -850 µm must be increased, and the +850 µm gold recovered as oversize. Once the +850 µm is extracted, sample size can be decreased to 50-70 kg for the standard test.

Table 3 also shows that within the same ore body, or even within different but contiguous ore bodies, there is a definite correlation between grade and GRG content. The implication is that the higher the grade, the coarser the size distribution of gold; this has been reported before for samples of the Witwatersrand reef (Splaine et al, 1982). This is in fact what is observed with the two Hemlo tests (Figure 7), as the second sample, at slightly higher grade, has more GRG than the first, all of it in the coarser size classes (as the two curves are parallel below 300 pm).

Table 3 Correlation Between Feed Grade and GRG Content for Samples of the Same Ore Body (*: indicates different ore types or zones)

Ore	Grade, g/t	GRG, %
MSV 1	2.9	60
MSV 2	3.5	65
Troilus 1*	1.0	52
Troilus 2*	1.44	56
Cadia 1*	1.0	33
Cadia 2*	1.4	70
Cadia 3*	1.8	86
Hemlo 1	9.9	61
Hemlo 2	10.8	73
Chimo 1	6.5	84
Chimo 2	11.3	94
Snip 1	45.1	61
Snip 2	27.4	58
Aur 1	1.0	27
Aur 2	9.3	35

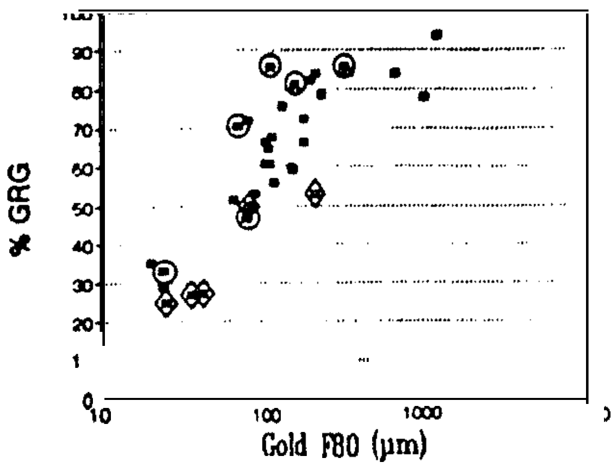
USES OF THE TEST

The test has a number of applications, some of which can lead to different diagnostics or outcomes. Table 4 summarizes the outcome of a number of actual tests.

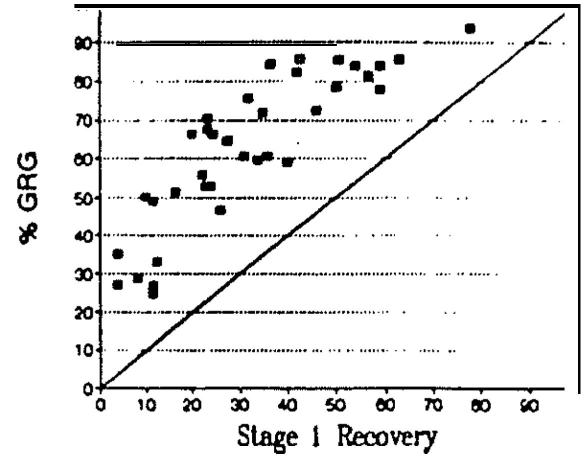
Condemnation

A first application is that of 'condemnation' testing. With a poor response (e.g., Figure 1, curve a), gravity can be almost ruled out as a process option. It is important that the test be capable of yielding such a result, as gravity recovery is not indicated for all ores. In at least one plant. where gravity had been designed in before the ore was tested, the poor response of the test was indeed correlated with an even poorer plant response. In this particular cas, the amount of liberated gold was reasonably good, but the high density of the gangue (mostly pyrite) and low density of the silver-gold alloys (closer to kustelite than electrum) hampered gravity recovery. In a number of cases, the outcome of the test put an end to gravity recovery research. Most of these were base metal applications.

Economic considerations have an important impact on the diagnostic of the test. For example, flotation of a copper-zinc ore is likely to direct most of the "free" gold into the



igure 5. Correlation between the F_{80} (gold and the %GRG



igure 6. Correlation between the GRC content and first stage gold recovery

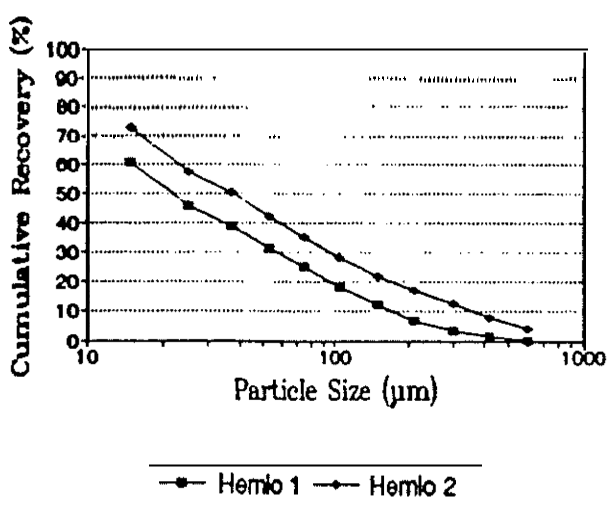


Figure 7. Results of the two Hemlo tests

copper concentrate, where economic payback is high. In the absence of copper, gold would almost certainly report to the zinc concentrate, where gold payback is usually nil. This would increase the incentive for some sort of selective gold recovery, either by gravity, selective flotation, or both.

Flowsheet Selection

The size distribution of the GRG is very useful in determining how gold should be recovered. This includes both the choice of recovery unit and feed preparation (usually screening). For example, it is pointless to present to the recovery unit a coarser fraction that is barren and lowers both its capacity and efficiency. This is especially appropriate for high density gangues, as coarse, high density particles can erode gold already captured by centrifuges (Laplante et al., 1995a). Prior screening would then be appropriate, at a size that should hinge on the coarsest GRG. If GRG is fine enough and the main process route is flotation, it may be more effective to use flash flotation, which can significantly decrease the circulating of GRG below 75 µm, and can even be followed by gravity recovery (Putz, Laplante and Ladouceur, 1993). In general, low density gangue ores are much more forgiving, and can yield good to very good gold recovery with relatively simple circuits.

Even when the response of the test is intermediate to highly amenable, results should be used cautiously. It should be understood that since the laboratory Knelson recovers gold very efficiently, actual plant performance will always be inferior to the measured GRG. By how much depends on the efficiency of the gravity circuit. Circuits that are extremely efficient can probably achieve a recovery equal to two thirds of the measured GRG, but this has never been observed in plant practice. The economic incentives of gravity recovery do not normally warrant achieving the full gravity potential. The Hemlo case is a helpful example (Laplante, Vincent and Luinstra, 1996). Two factors limit recovery. First, gravity is used only in the first of two loops in the grinding circuit, which implies that unliberated GRG in the primary cyclone overflow will never be recovered by gravity. Second, the recovery effort in the primary loop is limited to treating 25% of the circulating load, which is certainly reasonable. However, the PKC, at a feed rate in excess of 60 t/h, is overloaded, and its low GRG recovery corresponds to normal PKC operation with a much lower fraction of the circulating load treated. For example, at Camchib, the PKC stage recovery has been reliably measured at 70% GRG (Laplante et al., 1994). This could probably be achieved a Hemlo, but two, or even three 30" PKC would be required. It is highly unlikely that this would make economic sense at Hemlo.

The use of gravity recovery ahead of cyanidation has received mixed reviews. Hemlo is a typical case of very high recovery plant with no or little solution chemistry problems and no carbonaceous materials in the ore capable of adsorbing gold. The economic justification of gravity recovery is not overwhelming (although the gravity circuit was justified on very sound principles). In Australia, many cyanidation plants operate with difficult water chemistry (with dissolved solids in excess of 100,000 ppm in some cases), and Knelson-based gravity recovery has yielded increased overall gold recoveries of 1% or more in a number of plants (as well as significant savings in the operation of carbon circuits). Such benefits yield very rapid paybacks; unsurprisingly, a large number of Australian plants are now using Knelson (e.g Boddington, Paddington, Telfer, St.Ives and Howley).

Circuit Simulation/Optimization

To fully tap its potential, GRG data can be coupled with a mathematical description of GRG's grinding, classification and recovery to predict the performance of a gravity circuit. The basis for the model is discussed in Laplante, Woodcock and Noaparast (1995). and other case studies are presented in Laplante et al. (1995b) and Laplante, Vincent and Luinstra (1996). Simulation can be used for greenfield, retrofit and optimization applications. A sensitivity analysis with Hemlo data (Laplante, Vincent and Luinstra, 1996) strongly suggests that predicted gold recovery is far more sensitive to the GRG vector (amount and size distribution) than the performance of the recovery unit, the fraction of circulating it treats, or the final grind of the circuit. The grinding kinetics of GRG are even less significant. This confirms the importance of a sound characterization of the GRG content.

Ore Grade Estimation

Test work at the Tiblemont deposit (Laplante and Doucet, 1996) has shown how powerful the test can be to estimate gold content. The test must then be coupled with a sound sampling and sample reduction protocol. What the Tiblemont work suggests is that a single stage is adequate (as the calculated head of the second stage was in excellent agreement with the tail grade of stage I), which lowers the cost of the test substantially. Additional work showed that trying to lower the cost further by assaying only part of the Knelson concentrate after pulverization was counter-productive. The number of tails assays, however, could be reduced without significant loss of accuracy.

Others

The test can be used for more mundane applications. For example, fluctuations in the daily performance of a gold gravity circuit could be due to changes in mineralogy rather than circuit performance. Collecting and testing daily samples could easily confirm which of the two causes is dominant. At a South American plant, three ore types yielded very different GRG contents and size distributions. This explained much of the earlier fluctuations of the gravity circuit performance experienced before efficient blending was implemented. It can also be considered an applied mineralogy procedure, as it gives the amount of 'free' gold above 10 μm (the lower size range of applicability of the LKC), its size distribution and the grind at which it is liberated.

TABLE 4 A Summary of Some Common Diagnostics

Ore (main circuit)	GRG Test Results	Diagnostic	Reference(s)
Gold ore in Washington State (cyanidation)	29% GRG, but only 19% coarser than 25 pm	Discontinue gravity testing	Woodcock, 1984
Massive sulphide copper Ore in Quebec (flotation)	27% GRG, most finer than 100 µm	Discontinue operation of the gravity circuit	
Hemlo's Golden Giant Mine in Ontario (cyanidation)	60-70% GRG, some very coarse	Do not install a second Knelson or attempt gravity recovery in the second grinding loop	Banisi et al., 1991 Laplante et al., 1996 Honan, 1996
Highly weathered ore in Australia (flotation)	70-80% GRG, most very line	Flash flotation and gravity recovery from the flash concentrate	Putz, 1994 Putz et al., 1993
Three ores in South American Mine (cyanjdation)	60 to 85% GRG, with coarser, readily liberated gold in two ore types	Variations in the ore type ratio will cause significant performance shifts in gravity recovery	
Casa Beradi Ore in Quebec (cyanidation of a potential preg-robbing ore)	72% GRG, much of it very fine (-25 pm). presence of arsenopyrite	Recovery with a Knelson Concentrator from a -300 pm feed (fine screening)	Woodcock, 1994 Laplante et al.. 1995b Laplante et al., 1995c
Tiblemont Ore in Quebec	Very high GRG content with one recovery stage, feed of 0.04±0.01 oz/st	Discontinue surface exploration work	Laplante et Doucet, 1996
Base metal ore in Quebec (flotation/cyanidation)	Very high GRG content, with occasional very coarse gold	Recovery gold using a finer Knelson feed, to minimize concentrate bed erosion	Laplante et al., 1995a (lab work confiig impact of coarse dense feed)

CONCLUSION

A test to determine the amount of GRG was designed and tested on a wide variety of ores, Results can be used to assess the pertinence of using gravity recovery and to guide in circuit design. For plant where gravity recovery is already installed, the test can be coupled with a gravity recovery simulator to assist in the optimization of the gravity circuit.

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REFERENCES

Banisi, S., A.R. Laplante and J. Marois, 'A Study of the Behaviour of Gold in Industrial and Laboratory Grinding', CIM Bull., Nov. 1991, pp. 72-78.

Honan, S., Gravity Gold Concentration at Hemlo Gold Mines Inc., Golden Giant Mine' Proc. of 28th Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 1996, Paper 9.

Laplante, A.R., A. Putz, L. Huang and F. Vincent, Practical Considerations in the Operation of Gold Gravity Circuits, Proc. of 26th Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 1994, Paper 23. 21 p.

Laplante, A.R., L. Huang, M. Noaparast and N. Nickoletopoulos, 'A Philosopher's Stone: Turning Lead and Tungsten Into Gold -- The Use of Synthetic Ores to Study Gold Gravity Separation', Proc. of 27" Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 1995, Paper 28, pp. 379-394

Laplante, A.R.. F. Woodcock and M. Noaparast, 'Predicting Gravity Separation Gold Recovery', Minerals and Metallurgical Processing J., May 1995, pp. 74-79

Laplante, A.R., F. Vincent, M. Noaparast, F. Woodcock, A. Boulet, G. Dubé and J. Robitaille, 'Predicting Gold Recovery by Gravity', XIX Intern. Mineral Processing Cong., San Francisco, Oct. 199.5, Vol. 4, Chapter 4, pp. 19-25.

Laplante, A.R., Y. Shu and J. Marois, 'Experimental Characterization of a Laboratory Centrifugal Separator', Can. Metal. Quart., Vol. 35(1), 1996, pp. 23-29.

Laplante, A.R., F. Vincent and W. Luinstra, 'A Laboratory Procedure to Determine the Amount of Gravity Recoverable Gold', Proc. of 28th Ann. Canadian Mineral Processors Conf., Ottawa, Jan. 1996, Paper 8, 14 p.

Laplante, A.R. and R. Doucet. 'A Laboratory Procedure to Determine the Amount of Gravity Recoverable Gold', 1996 Annual Meeting of SME, Phoenix, March 1996, I Ip.

Putz, A., 'An Investigation of the Gravitv Recovery of Gold', M.Eng. Thesis, McGill University, Aug. 1994, 230 pp.

Splaine, M., S.J. Browner and C.E. Dohm, 'The Effect of Head Grade on Recovery Efficiency in a Gold-Reduction Plant', J. South Afr. Inst. Min. Metal., Jan. 1982, pp. 6-11.

Vincent, F., 'Comparing Jie and Knelson Performance', M.Eng. Thesis, McGill University, in preparation.

Woodcock, F. and A.R. Laplante, A Laboratory Method for Determining the Amount of Gravity Recoverable Gold, Randol Gold Forum, Beaver Creek, September 1993, pp. 151-155.

Woodcock, F., 'Use of a Knelson Unit to Quantifv Gravity Recoverable Gold in an Ore', M.Eng. Thesis, McGill University, Sept. 1994, 128 pp.