Ten Do’s and Don’ts of Gold Gravity Recovery

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Abstract

Ten guiding principles in the design and operation of gold gravity circuits are presented: economic impact, applied mineralogy, gold’s behavior in grinding circuits, alternate recovery approaches, reliability vs. performance, gold room operation, scale-up, screening, feed rate and recycling. The principles are explained and their application illustrated with case studies. Conflicts in principle application are also discussed.

Introduction

This presentation will review practical considerations of the design and operation of gravity circuits aimed at recovering metallic gold into a smeltable concentrate. The presentation will be based on good practice as observed over the years, and damnable mistakes observed and made. The do’s will generally correspond to existing practice in some plants, and these plants will be identified. The don’ts will also correspond to actual rather than virtual errors, and for obvious reasons, the plants where they were observed will remain anonymous. The only errors/blunders/misconceptions whose author will be identified will be his. Some of the don’ts will be caricatures, but the reader should not be mistaken: some of the errors reported were in the seven digits – nothing to laugh about.

In the presentation the do’s and don’ts will be explicitly linked. Reading similar material confirms that the link naturally exists between the two, and repetition can be avoided if the link is made. Similar material also suggests that the phrase “A ….’s View” (e.g. manufacturer, operator, builder) could be added to the title. The author, an academic, has been involved in the testing of over 60 ores for gravity recovery (over 70 tests), and has analyzed over 18 gravity circuits, many over a period of a few years (well over two-dozen sampling campaigns). Many more circuits have been visited. More significantly, the author has been privileged access to some of the shakers and movers of gold gravity recovery: inventors, practitioners, researchers, graduate students and maybe more importantly for this contribution, operators. It is the experience and wisdom of these people that will be distilled here; the author would like to acknowledge their contribution. Having said this, the academic side of this presentation cannot be denied, and most do’s will be basic principles from which specific observations and recommendations will be derived.

Once the ten do’s and don’ts have been presented, the recommendations will be summarized. Like other design problems, the design of gold gravity recovery circuits is constrained, which means that some of the basic recommendations
cannot be simultaneously applied. Some of the most obvious conflicts will be identified and discussed.

**Do #1: Try to Evaluate the Economic Impact of Gravity Recovery**

**Don’t #1: Go for the BMW of Gravity Circuits: Nothing Can Be Too Good!**
(Or the opposite: don’t buy a car now, wait until later)

The author is a strong proponent of gold gravity recovery, but for nearly all projects, gravity recovery is not as economically significant as grinding or flotation/cyanidation performance. This should be factored in the designed gravity recovery effort.

The economic benefit of a gravity circuit is at worst, the (negative) cost of installing and running it (in the absence of any benefit). At best, it is probably at the level of 5% of the gold value in the ore. In some rare cases is it higher.

The highest economic impact for gravity recovery has been observed when the gravity recoverable content (GRG) content is high and coarse. At least three distinct cases have been observed: (A) flotation of a copper concentrate from a low copper grade feed, (B) selective flotation of a Cu-Zn-Pb or Cu-Zn or Pb-Zn ore and (C) cyanidation of a coarse feed at coarse grind without a thickener between grinding and cyanidation. Some ores that are exceptionally preg-robbing may also warrant an exceptional gravity recovery effort (Lewis, 1999).

Evaluating the economic contribution of gravity recovery is a very challenging exercise for just about any ore other than the ones identified in the previous paragraph. The lower the benefit, the more difficult it is to measure. Gravity recovery has the lowest economic impact when running a cyanidation circuit with ample residence time, in very clean water (low total dissolved solids, TDS), optimized and well controlled cyanidation chemistry, a very fine grind and with a clean ore (no preg-robbers, low sulphide content). In such a situation, it is unclear whether a gravity circuit should be installed at all (although some benefits are difficult to quantify, and could easily be overlooked). The author has had access to good monthly operating data from such plants compiled before and after the installation of a gravity circuit, and in all cases but one the impact of gravity recovery could not be demonstrated at a 95% confidence level, because of normal data scatter. This scatter can originate from feed grade variations, changing mineralogy, evolving plant practice, etc... Yet in most of these cases plant personnel were convinced that gravity recovery had increased overall recovery. For example, a significant decrease in the number of peaks in tailing assays had been observed. Other benefits, such as reduced gold inventory or a lower frequency of carbon strips, had also been achieved.
Faced with the problem of justifying gravity recovery, varying approaches have been suggested. One that is generally not satisfactory is to target GRG in the final tailing, hoping to achieve an easily observable benefit. This approach very seldom yields any measurable benefits, because GRG in the final tailing is predominantly too fine or too flaky for effective gravity recovery. Furthermore, targeting this stream does not yield some of the important benefits associated with gold gravity recovery upstream, such as reduced carbon transfers. Final tailing should only be targeted if gold-bearing sulphides can also be recovered and re-processed (see #4).

Another unsatisfactory solution is to wait until after plant start-up to retrofit a gravity circuit. This approach fails to minimize the accumulation of an unwanted gold inventory (i.e. where gold particles are likely to settle) at start-up, a time of important cash flow considerations, and very often leads to a less than acceptable circuit layout (as many retrofits do).

A reasonable compromise when faced with uncertain gravity economics is to design a gravity circuit with a low recovery effort (defined in Laplante and Xiao, 2000) that will be operative at mill start-up. This approach is contingent upon the ore having enough GRG, typically above 60% (as was the case of the majority of the 70 samples tested for GRG). Retrofitting a higher recovery effort could take place once the economics of gravity recovery are better defined, and could include (A) better screening ahead of primary recovery, (B) more primary recovery units, and (C) scavenging of the table tails in the gold room.

Do #2: Get a Statistically Significant Sample of the Ore to Evaluate Gravity Response on a Size-by-Size basis

Don’t #2: Extract a Large Number of Samples, Look for a Few Gold Grains, Preferably Very Large Ones, and Use them to Justify Circuit Design

As discussed in the first point, gold gravity recovery generally has a modest impact of 1 to 3% on overall recovery. This should be understood at the design stage. The implication is that a costly test program is generally not warranted. What is needed is a representative sample of the mill feed of suitable mass from which the size distribution of the gravity recoverable gold (GRG) can be extracted. Gold gravity recovery should then target most gold particles rather than the exceptionally coarse particles.

A GRG test is available to yield the information needed for gravity circuit design and performance prediction (Woodcock and Laplante, 1993). For most applications where the impact of gravity is “modest”, a single test is sufficient.

This second point does not rule out scoping work that uses a gravity step prior to flotation or cyanidation. However, the gravity step is then used to provide a
more realistic feed to the downstream recovery step, rather than for gravity circuit design or performance prediction (Laplante, 2000).

This point does not rule out either the need to use piloting for larger or metallurgically challenging projects. Gravity recovery would then be used in the pilot flowsheet, but again with the objective of providing downstream recovery with a more realistic feed. The GRG test could then be a cost-effective means of treating various ore types.

In one instance, the author was contacted by a metallurgist who had collected and separately tested over 400 2-kg samples for gravity recovery, for a retrofit project. The metallurgist marveled that both grades and gravity recoveries were “all over the map.” This would be predicted from mere sampling statistics. A single composite should have been tested for its GRG content, with much more reliable and easily analyzed results, produced at a much lower cost.

Do #3: Design the Gold Recovery Circuit with a Good Understanding of Gold’s Behavior in Grinding Circuits

Don’t #3: Gold Gravity Is Just Like Any Other Gravity Recovery

Gold’s behavior in grinding circuits is the result of its malleability and specific gravity, which combine to yield high circulating loads, especially in the fine sizes (typically below 75 µm) (Banisi, Laplante and Marois, 1991). The specific rate of breakage of gold is lower than that of all ores, as shown in Figure 1. It therefore moves only slowly from its natural grain size into finer size classes, where it still reports to cyclone underflows much more readily than cyclone overflows, as shown in Figure 2.

![Figure 1](image-url)

**Figure 1** Specific Rate of Breakage of Gold and Ore at Golden Giant Mine (From Banisi, 1990)
The following statements are generally applicable:

1. Gold grinds between 5 and 20 times slower than its gangue.

2. About 99% of all GRG fed to a cyclone reports to its underflow, unless it is a primary cyclone in a two-stage classification circuit.

3. GRG below 25 µm still reports to cyclone underflows in a proportion ranging between 75 and 95%.

4. Gold particles above 75 µm circulate between 50 and 100 times in a grinding circuit, unless they are recovered by gravity.

5. Once a particle of GRG breaks, more than 90% of its fragments are gravity recoverable.

The behavior described above means that only part of the circulating load has to be treated for gravity recovery, and that fine GRG recovery is important, since much of the coarser GRG that is not recovered by gravity will accumulate in the grinding circuit as finer GRG. This in a nutshell explains why Knelson Concentrators have been so successful for GRG recovery: although they cannot treat the full circulating load, they excel at fine GRG recovery.

Since 99% of the GRG reports to cyclone underflows, the 1% that reports to overflows must be considered “deviant” and its gravity recovery more challenging than that of GRG in cyclone underflows. In circuits where GRG content was measured, the amount of GRG in the grinding circuit final overflow has never reached that of the ore, even when no gold was recovered by gravity (i.e. all of the GRG reported to the final overflow). Typically, in ores when 60 to 80% of the gold is gravity recoverable, only 15 to 30% of the gold in the final cyclone overflow is gravity recoverable. In all the grinding circuit surveys analyzed by the McGill University research group, the primary cyclone underflow has always been the best candidate for gravity recovery (i.e. the highest concentration of GRG).
The primary cyclone overflow of a two-stage classification circuit may contain substantial GRG, depending on how the primary cyclones are operated, but never at a higher concentration than the primary cyclone underflow.

From the above considerations, it is clear that for GRG recovery, the primary cyclone underflow is the best candidate to gravity recovery, either as is or after it is ground in the secondary mill.

**Do #4: When GRG Recovery Is Not Indicated, Look at Other Options**

**Don’t #4: Try to Produce Bullion By Gravity at All Cost (literally…)**

One must be able to take no for an answer. GRG gravity recovery seldom makes economic sense when the GRG test yields less than 50% GRG, the gangue has a high specific gravity or the GRG is particularly fine.

Faced with the above verdict, one can decide to plough ahead and install a GRG gravity circuit “just in case.” It has been done, with dismal (but predictable) results.

Another reaction may well be to accept the verdict, but to look at a different approach to optimize gold recovery. This has been often done with great success.

At Aur’s Louvicourt Mine, where GRG content was low, fine, and high in silver (with a low GRG specific Gravity), flash flotation was successfully used to cream a high grade copper concentrate that recovered most of the GRG. Gold, copper and zinc recovery increased, yielding a NSR well in excess of one million US$ per year. Newcrest also used the same approach at Cadia (the flash flotation concentrate is reground and cyanided), where the GRG content was high but fine. Flash flotation can recover GRG as coarse as 212 μm and is even more effective than gravity recovery if the objective is to lower gold’s circulating load in grinding circuits at sizes below 106 μm. Flash flotation does introduce surfactants that may be unwanted in a downstream cyanidation circuits, but is very appropriate ahead of a conventional flotation circuit.

At New Celebration (Newcrest) and Granny Smith (Placer Dome), spirals and Reichert cones are used to scavenge partially leached GRG and gold-bearing sulphides from a cyanidation tailing. The gravity concentrate is reground in vertical mills and recycled to the head of the cyanidation circuit. There is some evidence that centrifuge units could recover even more gold than the existing circuits (Butcher, 2000).

At Echo Bay’s Kettle River, a continuous Falcon Concentrator (C4000) is used to pre-concentrate part of the cyanidation circuit feed. This concentrate is fed to the first tank of the cyanidation circuit where it is given a very high retention time.
It then joins the Falcon tailing into the second cyanidation tank. Gains in gold recovery are variable, but average 1.5%. Kettle River is an ore with a low GRG content.

### Do #5: Design the Circuit for Ease of Operation and Mechanical Reliability Rather than Absolute Performance

### Don’t #5: Design the Circuit to Maximize the Recovery Effort … Most of the Time

This point may not at first be evident. Should not one try to maximize the recovery effort to maximize the benefits of gravity recovery? Even if the resulting circuit is more unwieldy? The answer lies partly in Figure 3, which shows the recovery of a gravity circuit as a function of the recovery effort (% of the GRG of the circulating load that is recovered), (Laplante, 2000). The model is based on Laplante, Naoparast and Woodcock, 1995. The horizontal scale is logarithmic, and each point is obtained by doubling the fraction of the circulating load treated of the previous point on the curve, at constant recovery of 60% for the fraction treated. Once 70% of the GRG has been recovered, at a recovery effort of about 2 to 3%, the curve plateaus quickly. The next twofold increase in recovery effort, which is probably close to a twofold increase in capital cost, would only increase GRG recovery by about 10%, up to 80%.

![Figure 3](image.png)

**Figure 3**  GRG Recovery as a Function of the Recovery Effort (Laplante, 2000)

This begs the following question: which is best, reliability or performance? The bottom line is that when a gravity circuit is down, typically because of screening or pumping problems, there is no gravity recovery. We illustrate with an example: consider a gravity circuit with an availability of 95% at a recovery effort of 2.5%, which would give a GRG recovery of 70% when the gravity is running (see Figure
3), or 67% overall. If, for example, the above recovery effort is doubled, gravity recovery increases only slightly, to 80%. Should availability then go down dramatically, say to 80%, overall GRG recovery would actually drop from 67% to 64% (80% of a GRG recovery of 80%). Simulation shows that a 1% relative increase in circuit reliability increases overall recovery by as much as a 4% relative increase in recovery effort.

In the above example, it may be argued that a drop in availability of 95 to 80% is unrealistic. This is not the case. Gravity circuit operation can be challenging, because the material treated is typically difficult to pump (i.e. a cyclone underflow, Knelson concentrates). Screens are likely to puncture resulting in downstream pumping or sanding problems. Repairs and maintenance that would require a plant shutdown are delayed until the next scheduled shutdown, because “gravity is not essential.” Performance improvements in the first years of operation of a gravity circuit are more likely to stem from better availability than better recovery when running. Improvements in operating availability of recently installed gold gravity circuits from about 50% to more than 90% have been reported to the author more than once. Because of the rapidly diminishing return of the recovery effort, it is clearly better to design with reliability in mind.

Reliability should also be extended to the other units of the grinding circuit from which gold is recovered. Often overlooked is the problem of severe grinding circuit upsets that will flush out of the circuit a substantial part of the circulating load of GRG that has accumulated since the last upset. Some of this material would then arrive to the cyanidation circuit at a particle size too coarse for complete cyanidation; gold losses would increase. Because coarser gold particles can have a very long residence time in grinding circuits (at their original size or as progeny), often in the order of magnitude of a few hours, they are particularly vulnerable to this problem.

Gravity circuit reliability can be designed into a circuit: safety screens in pump sumps (see #8), magnetic separators to remove coarse tramp iron, pipes with enough vertical drop to prevent sanding, etc... When using units in parallel, additional piping and transfer boxes can introduce operational flexibility. Providing easy access for repair and maintenance can reduce downtime.

Do #6: Improve Gold Room Performance

Don’t #6: Focus Only on Primary Recovery

In this section a recent presentation will be summarized (Laplante, Huang and Harris, 1999) on gold room practice. Gold room recovery has a significant effect on overall gold recovery, although this effect is partly offset by the circulating load between the gold room and the grinding circuit. Reported gold room recoveries appear to vary between 50 and 97%. The implication is that some gold rooms are
superbly operated, whereas others are not recovering GRG that has already been upgraded into a very small mass.

A survey of GRG content in gold room table tailings from 15 plants showed that in all cases but one, most of the gold was finer than 150 μm. Of the gold in the –150 μm fraction, at least 80%, and often more than 90% could be recovered with a 3-in Knelson Concentrator. Almost all of the gold particles in the –150 μm fraction observed by scanning electron microscopy were liberated. This would indicate that variations in observed gold room recovery are much more a function of tabling practice than mineralogy.

The recommendations of the above paper can be summarized as follows:

1. Proper design of the concentrate receiving tank, to minimize entrainment of fine gold with the return water.
2. Proper design of the bottom of the tank for easy concentrate removal: taper, water addition, and correct choice of valve.
3. Screening and magnetic removal of tramp iron from concentrate prior to tabling.
5. Recovery of spillage on the floor of the gold room (to be pumped to the primary concentrate tank).
6. Recycling of the tails from the gold room to the primary gravity unit.
7. Nitric acid treatment of the final concentrate when copper blasting wire is used.
8. Design of the gold room for headroom as much as floor space, to take advantage of gravity flow.
9. Recycling of the cleaner table tailing and rougher table middling to the primary concentrate hopper.
10. Intensive cyanidation of primary concentrate or table tails if appropriate.

The last point is an addition to those from the reference: intensive cyanidation using an automated system such as Gekko’s in-Line Leach Reactor (ILR) (Gray and

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1 The author once recommended using the centrifuge ahead of tabling. This was a mistake, as the high gold content of the feed (a primary centrifuge concentrate) caused the centrifuge unit in the gold room to overload too quickly.
Katsikaros, 1999), should be considered when the incentive of gravity recovery is high. At Kundana Mine, treating the table tails with a ILR unit increased overall gold recovery by 1.5%. Other units are now available for the treatment of gravity concentrates, such as the Acacia reactor (Anglogold), the modified Minataur process (Mintek) and the Consolve system (Knelson Concentrators). All were presented at the Randol 2000 and should be referenced in the proceedings.

The presentation included a simple economic analysis of gold room flowsheet. It concludes that a second shaking table, a magnet, a screen and small capacity centrifuge can be justified on the basis of the added gold recovery or reduced processing time.

**Do #7: Be Aware of Scale-up Problems**

**Don’t #7: Assume that Laboratory Recoveries Are Easily Reproduced at Plant Scale**

The differences between typical scoping gravity work or the GRG test discussed in the first “do” and the way centrifuge-based gravity recovery is effected at plant scale are very significant. The more important ones are outlined in Table 1 (Laplante, 2000).

**Table 1**  
Gravity Recovery: Some Differences between Scoping Work, the GRG Test and Centrifuge-Based Plant Practice

<table>
<thead>
<tr>
<th>Scoping Work</th>
<th>GRG Test</th>
<th>Plant Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific feed rate low</td>
<td>Specific feed rate low</td>
<td>Specific feed rate high</td>
</tr>
<tr>
<td>Single pass, at final grind size</td>
<td>Three passes at progressively finer grinds</td>
<td>Each particle fed a large number of times (potentially), with the size distribution of the screened circulating load</td>
</tr>
<tr>
<td>Primary yield very high, 2-5%</td>
<td>Yields of 0.15%, 0.3 and 0.4% for the three stages</td>
<td>Primary yields of 0.05 to 0.10%</td>
</tr>
<tr>
<td>Cleaning with amalgamation or hand panning</td>
<td>Microscopic examination of gold particles above 150 μm</td>
<td>Cleaning in gold room to smeltable grade</td>
</tr>
<tr>
<td>Feed without tramp iron</td>
<td>Feed without tramp iron</td>
<td>Abundant tramp iron in SAG circuits</td>
</tr>
<tr>
<td>Manual materials handling</td>
<td>Manual materials handling</td>
<td>Material pumped as a slurry</td>
</tr>
</tbody>
</table>

The first point is critical, because the differences in specific feed rate (in t/h per m²) are very significant. Typical scoping work is performed at 0.5 kg/min; the
GRG test uses feed rates of 0.4 kg/min (third stage) to 1.3 kg/min (first stage). These feed rates, if scaled up for 20-in and 30-in Knelsons operated at the same specific feed rates, would correspond to a range of 1-3 t/h for a 20-in Knelson and 2-8 t/h for a 30-in Knelson. In practice, feed rates in full-scale circuits are at least tenfold what the scale-up criterion suggests.

There is some evidence that where full scale feed rates are indeed very low, unit recovery approaches that of the laboratory Knelson (Putz et al., 1993). However, typically feed rates are much higher (as they should, see #9), and measured GRG stage recovery varies anywhere between 10 and 60% (i.e. the full-scale unit recovers between 10 and 60% of what the laboratory unit can recover). Strong evidence also shows that as the specific gravity of the gangue increases, the effect of a higher specific feed rate becomes much more significant.

The second and third points of Table 1 should be considered together. In plants, primary Knelson concentrates typically assay between 5,000 and 50,000 g/t, owing to their low weight recovery. Virtually all (i.e. 98% or more) the gold recovered is GRG (Laplante, 2000). Although the practice of intensive cyanidation of these concentrates is slowly growing (Gray and Katsikaros, 1999), the vast majority of the recovery is still effected with shaking tables to produce a high-grade concentrate, often assaying as much as 80% gold.

Bench scale practice is very different. Primary concentrates are produced with very high yield in scoping work, requiring a significant cleaning stage that is performed with hand panning or amalgamation. Primary recovery is very likely to overestimate the amount of GRG in the ore and plant performance. The cleaning stage will reject most of the gold that is not liberated, but neither panning nor amalgamation fully mimic the gold room. The GRG test uses lower yields and microscopic examination of the coarsest gold particles can diagnose liberation problems, but the problem of concentrate grade remains.

The last three points in Table 1 exemplify the difficulties of running a full-scale gravity circuit within the circulating load of the grinding circuit, as opposed to well-controlled laboratory tests. The recovery achieved at laboratory scale is not likely to be matched in plant practice.

The above discussion leads to the most important question: can full-scale recovery ever match laboratory results? Virtually all the points of Table 1 would suggest that plant recovery should be much lower than that of the laboratory. However, the one redeeming feature of full-scale circuits is the large circulating load of gold that presents the same gold particle or its progeny more than once to the primary recovery unit. It is necessary to understanding the dynamics of the lower full-scale stage recovery and high circulating load to establish the link between GRG content (or any other bench-scale procedure) and full-scale performance.
When using a centrifuge for recovery from a stream other than a circulating load, *stage* recovery becomes much more critical, and specific feed rates should be scaled up if laboratory performance is to be used as a predictor of plant performance. This decreases the capacity of the full-scale units very significantly.

**Do #8: Pay Attention to Screening**

**Don’t #8: Don’t**

Treating a relatively coarse feed is appropriate if GRG is coarse (a substantial fraction coarser than 300 μm) and gangue specific gravity low (i.e. mostly silicates and carbonates). When gangue specific gravity is high gravity (i.e. more than 50% sulphides or iron oxides) and GRG finer (mostly below 212 μm), using a finer feed is a better course of action. For separations that rely extensively on gravity separation (e.g. tin, coal), this removal of the coarser fraction to feed a more narrowly sized product is called feed preparation, or simply “feed prep”. For difficult gold recoveries, it becomes essential. Already, most gravity recovery manufacturers recommend some form of coarse screening ahead of their unit. This step, however, is at generally coarse mesh, for example 2 to 5 mm for Knelson Concentrators. For difficult separations, the feed should be as finer as economically and practically possible. For example, if a GRG finer than 212 μm is to be recovered from a gangue containing about 10% arsenopyrite (s.g. 6.0), the feed should be screened at 300 to 500 μm, not 2 to 5 mm. The finer feed will have a much higher GRG content, require a lower fluidization back flow in the centrifuge unit, and yield a higher recovery and more easily treated concentrate.

In the gold room, screening of the table tails at 150 to 212 μm to process the undersize with a smaller centrifuge can increase recovery very significantly (Huang, 1996). Sadly, most plants that have successfully implemented centrifuge-based scavenging of table tails have resisted pre-screening, despite its relatively low cost in a gold room. Laboratory work with a 3-in Knelson clearly showed that pre-screening does increase recovery significantly, typically by a relative 50%.

Some of the “do’s” presented here are not easily reconciled. For example effective fine screening ahead of primary recovery is costly, and the relatively low impact of gravity recovery calls for cost-effective solutions. What is the best course of action? The author knows of two plants that retrofitted screens at significant cost (cyclopacks had to be lifted and structural steel added) to accommodate screens on already operating Knelson Concentrators. In one case, the decision may have been unwise, as gravity recovery did not increase significantly once the screens were operational. One could surmise that if ideal screening cannot be retrofitted at reasonable cost, it is better to increase the frequency of concentrate removal, screen the Knelson concentrate in the gold room, and install a larger concentrate hopper to accommodate the increased concentrate mass.
A recent development presented at the Randol 2000, the Pansep screen, could provide affordable screening at 150-300 µm for separations with fine GRG content (Buisman and Fullam, 2000). This could significantly impact on gold gravity recovery, as finer feeds would result in increased head grade, better recoveries and extended recovery cycle, especially when gangue specific gravity is high (Laplante, A.R, Huang and Harris, 1996).

Surrogates for screening can also be used in certain conditions. For example, some primary cyclone underflows feed ball mills whose discharge is much finer than the cyclone underflow. In such cases, recovery from the mill discharge may be the preferred solution, especially if a significant proportion of the circulating load is to be treated for gravity recovery (see #9). The finer mill discharge relaxes screening requirements, and in some cases may eliminate entirely the need to screen. Another surrogate is a low intensity magnetic separator (LIMS), which can assist or even replace screening whose main objective is tramp iron removal (i.e. scats). This approach can also be beneficial in the presence of a significant magnetite content in the ore.

Finally, in cases where the rejection of coarse oversize is critical, the regular screening step may be complemented with static “safety” screens for rapid detection of screen puncture. At Omai Mines, static screens are used in pump sumps located between regular vibrating screens and Reichert Cones. Cameras aimed at the sumps make it possible to detect screen failure rapidly. This has resulted in a significant increase in the availability of the gravity circuit.

Do #9: “Overfeed” the Primary Unit

Don’t #9: Maximize Primary Stage (Unit) Recovery

One of the most common operating mistakes observed when visiting plants is the operation of centrifuge units at low to very low feed rates. Feed rates as low as 0.3 t/h for a 21-in Falcon SuperBowl, 3 t/h for a 20-in Knelson Concentrator or 10 t/h for a 30-in Knelson Concentrator have been reported to or measured by the author. Figure 4 shows that at low feed rate, GRG stage (or unit) recovery can be exceptionally high (20-in Knelson Concentrator). From an operational perspective, this is primarily an indication of insufficient feed rate. More gold could be recovered by increasing feed rate to the unit, even if stage recovery would then drop substantially. Figure 4 also shows what the size-by-size recovery should look like for a similar unit (30-in Knelson Concentrator at Est Malartic).

Using high feed rates can clash with the ability to screen this material at the proper mesh size. It would appear that when gangue specific gravity is low, the best solution lies on the side of high throughputs at coarse size rather than lower throughputs of a finer product. With a higher specific density gangue, coarser feeds...
seriously hamper gravity recovery, and a very effective screen must be used ahead of gravity recovery.

![Graph showing GRG Recovery](image)

**Figure 4** Size-by-Size GRG Recovery for a 20-in Knelson Concentrator at 3 t/h and a 30-in Knelson Concentrator at 30 t/h (With a high specific gravity gangue feed)

The 20-in and 30-in Knelson Concentrators can be supplied with a screening unit that fits above the cone and probably benefit from the vibrations generated by the rotating cone (although the vibration level is low). This screen provides a convenient and inexpensive means of removing oversize, but it is not as effective as a stand-alone vibrating unit. Many plant operators have found it necessary to open the mesh of the Knelson screen to about 4 to 6 mm to maximize tonnage to the underflow and recover some of the coarser gold (e.g. Golden Giant, Campbell, Dome). It is likely that the resulting increases in recovery were due to the higher feed rate to the Knelson rather than the recovery of the coarsest gold particles. Openings of 4 to 6 mm are also often reported in Australian mills treating oxidized ores with coarse GRG. Knelson Concentrator now offers units with increased screen surface. For difficult separations requiring a finer feed, a separate vibrating screen should be used. The high capacity of the Pansep screen (presented in #8) also offers an interesting alternative.

In a typical circuit where part of the primary cyclone underflow is bled and fed to a centrifuge unit, the unit tail is directed to the ball mill discharge, to avoid using an additional pump and diluting the ball mill feed. As a result, material that was classified and should have been fed to the mill returns to classification. For high gravity recovery effort, such a large fraction of the circulating load must be treated to feed the centrifuge unit(s) adequately that it makes more sense to treat the ball mill discharge rather than cyclone underflow. No material reporting to the cyclone underflow then by-passes ball milling. Ultimately, the full ball mill discharge can be treated. The other approach is to use a plant layout that makes it possible to return the tails of the gravity unit to the mill. At the Kundana mine, a 20-in Knelson
Concentrator treats as much as 120 t/h of cyclone underflow, and its tailing is fed to a ball mill. Despite the obvious excess feed rate and resulting low stage recovery, very high gravity recoveries are achieved, significantly more than two thirds of the GRG content in the ore.

**Do #10: Recycle**

**Don’t #10: Keep Operation “Simple” by Avoiding Recycling**

Because gold gravity circuits are relatively simple, there is little thought of the possibility of improving gravity recovery by making flowsheet changes. However, applying a principle as simple as recycling the tailing of one stage to the feed of the previous stage can boost gravity recovery. The principle is simple: consider a two-stage circuit with stage recoveries of $R_1$ and $R_2$, respectively. Let us consider two cases, open and closed circuit operation, shown in Figure 5.

![Open and Closed Two-Stage Circuits](image)

**Figure 5**  Open and Closed Two-Stage Circuits

It is easily demonstrated that recovery for the open circuit is $R_1 \times R_2$, whereas for the closed circuit it is $\frac{R_1 \times R_2}{1 + R_1 \times (R_2 - 1)}$. The relative increase in recovery of the closed over the open circuit is shown in Figure 6.

![Relative Recovery Increase](image)

**Figure 6**  Relative Recovery Increase Achieved when Closing a Two-Stage Open Circuit (legend: fractional recovery of stage 2)
Figure 6 shows that the relative increase in recovery is most significant when stage 1 recovery is high and that of stage 2 is low. Even when both recoveries are around 0.5, the relative increase is a significant 33%.

At Cambior’s Lucien Béliveau, the gold room table tails was recycled to the primary 30-in Knelson Concentrator, with a relative increase in recovery of approximately 25%.

At Omai Mines, Reichert Cones produce concentrates treated with 30-in Knelson Concentrators. Both tailings were returned to the grinding circuit. Recycling the Knelson tails to the Reichert Cones contributed to an increase in gravity recovery of approximately 40%. Stage recovery for GRG had been measured at 90% for the cones and 70% for the Knelsons. Figure 6 suggests that a relative improvement of 37%, in good agreement with the observed improvement.

Other normal recycling practices should include recycling gold room tails to the feed of the primary recovery unit, and in the gold room, table middlings to the primary concentrate hopper and secondary table tails to primary table feed. These practices have been observed in some, but by no means all operations visited.

![Figure 7](image)

**Figure 7** Overall GRG Recovery as a Function of the Fractional Recovery Effort and Probability of GRG Cycle Survival

A typical gravity circuit can be represented by the closed-circuit of Figure 7, where $R_1$ is the probability than a GRG particle will go once through classification and grinding and survive as GRG (= probability of cycle survival), either in the original particle or its progeny. $R_2$ is the overall recovery effort. $R_1$ is known to be very high, above 0.9, and $R_2$ very low, between 0.01 and 0.15. Figure 7 shows that with the range of GRG cycle survival probability and recovery efforts normally encountered, overall GRG recovery can vary from 10% to 90%. Irrespective of the recovery effort, cycle survival probability, which is very much a function of classification, has a significant effect on overall GRG recovery. Hence it is impossible to predict what GRG recovery will be without taking classification into
account. Ineffective classification will lower gravity recovery, because more GRG will report to the cyclone overflow, thereby lowering the probability of GRG cycle survival.

Poor cyclone separation can also lower gravity recovery in a second way. In a mill where the gravity circuit was retrofitted, changes from a single well-adjusted cyclone per line to a poorly adjusted cyclopack boosted the circulating load from 400% to 800%, much of the increase stemming from a very large short-circuiting (by-pass) component that carried very little GRG. The gravity circuit could not treat the designed proportion of the circulating load. The resulting drop in recovery effort had a very adverse effect on gravity recovery. Interestingly, only the classification efficiency of the cyclone whose underflow feeds the primary classification is at stake here. Thus, if a cyclone is dedicated to the gravity circuit, it may well be operated differently from the other cyclones. For example, it may be operated with a smaller apex diameter to minimize short-circuiting of low GRG content material. This idea, if pushed very far, may even lead to different cyclone geometry, to maximize the effect of particle specific gravity and minimize that of particle size. If the overflow of the dedicated cyclone is not fine enough to be combined to the main overflow, it can be recycled to cyclone feed.

Summary and Conclusion

Table 2 attempts to summarize the material presented here. Each suggestion is linked to the “do’s” from which it originates and where it is justified.

Most recommendations are not mutually exclusive, but some are. Obviously, one cannot decide to scavenge gold room tails with a centrifuge and intensive cyanidation. Similarly, recovering GRG from the grinding circuit using gravity and flash flotation is generally unsatisfactory, since flash flotation will purge the circulating load of GRG below 105 to 212 μm and lower the efficiency of gravity recovery. Gold cannot be recovered both from the cyclone underflow and the ball mill discharge.

The most challenging compromise remains that of reconciling the first do with most others. For example, screening at the correct size and providing enough underflow rate is easily achieved when the cut size is around 4 mm, but what if finer cut-sizes are needed or desirable? Will the designers use the foresight needed for the additional capital outlay for screening? When will the first centrifuge-based scavenging circuit (to recover gold bearing sulphides) be installed in the gold industry? It may be that environmental pressures aimed at cyanidation circuit will provide the incentive for more effective gravity circuits. This is already happening in some locations (Montana) and has led in Ukraine to the commissioning of a mill that uses gravity as the sole recovery method (Grodowski and Van Kleek, 2000). The other likely push will be economics: as gold prices stagnate around 280 US$, it will become increasingly necessary to grind coarser, cyanide coarser feeds for less
time, or float coarser feeds. A better understanding of how the economic impact of gravity recovery can be predicted would also be of great use, as capital expenditures must always be weighed against their economic benefits.

References


Buisman, R. and M. Fuller, A Novel Approach to Fine Screening: the Pansep Screen, Randol Gold and Silver Forum, April 2000

Butcher, G. (1999), personal communication


Table 2  Recommendations: A Summary

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>From #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan a recovery effort in line with economic benefit of gravity</td>
<td>1</td>
</tr>
<tr>
<td>When coarse gold is present, plan to commission gravity recovery at plant start-up</td>
<td>1</td>
</tr>
<tr>
<td>Design a low start-up recovery effort and flexibility to increase it when economic benefit is uncertain</td>
<td>1</td>
</tr>
<tr>
<td>Characterize gravity recoverable gold for circuit design and prediction of recovery</td>
<td>2</td>
</tr>
<tr>
<td>Do not perform many tests with small feed mass and high yield for the sole purpose of characterizing gravity recovery</td>
<td>2</td>
</tr>
<tr>
<td>Target the primary cyclone underflow for GRG recovery</td>
<td>3</td>
</tr>
<tr>
<td>Recovery of fine gold, even below 25 µm, is more important than treating the full circulating load</td>
<td>3</td>
</tr>
<tr>
<td>Look at other options: flash flotation and gold-bearing sulphide recovery</td>
<td>4</td>
</tr>
<tr>
<td>Design a reliable and flexible gravity circuit to achieve high availability</td>
<td>5</td>
</tr>
<tr>
<td>Include screening, magnetic separation and a second table in the gold room</td>
<td>6</td>
</tr>
<tr>
<td>Recover free fine gold from gold room tails</td>
<td>6</td>
</tr>
<tr>
<td>Leave yourself enough head room in the gold room for flexible operation</td>
<td>6</td>
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<tr>
<td>Be aware of the difference between laboratory scale and full-scale centrifuge unit operation, in particular with respect with the effect of the gold circulating load</td>
<td>7</td>
</tr>
<tr>
<td>Open circuit centrifuge units must be operated at much lower feed rates</td>
<td>7</td>
</tr>
<tr>
<td>For difficult separations, be willing to spend more on screening at the proper feed size</td>
<td>8</td>
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<tr>
<td>Use static safety screens ahead of size sensitive units</td>
<td>8</td>
</tr>
<tr>
<td>The need for screening can be minimized by careful selection of the primary gravity feed (i.e. a ball mill discharge) or by using another separating device (LIMS)</td>
<td>8</td>
</tr>
<tr>
<td>Screen at the proper mesh size and design enough screen underflow rate (capacity) to feed the centrifuge unit adequately</td>
<td>8,9</td>
</tr>
<tr>
<td>For retrofit projects, it may be more cost effective to screen in the gold room rather than before the primary recovery unit</td>
<td>1,8</td>
</tr>
<tr>
<td>Maximize feed rate to primary recovery units</td>
<td>9</td>
</tr>
<tr>
<td>For high recovery efforts, treat ball mill discharge rather than primary cyclone underflow</td>
<td>9</td>
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<tr>
<td>Operate recovery units in closed rather than open circuit</td>
<td>10</td>
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<tr>
<td>Adjust the classification efficiency of the cyclone dedicated to gravity recovery to optimize the GRG content of its underflow</td>
<td>10</td>
</tr>
<tr>
<td>Optimize classification to increase the circulating load of GRG</td>
<td>3,10</td>
</tr>
</tbody>
</table>
References


References


Darnton, B., S. Lloyd and M.A. Antonioli, Gravity Concentration: Research, Design and Circuit Performance at Montana Tunnels, Randol Gold Forum Vancouver '93, pp. 137-143

Keran, V.P., F. Zumwalt and J. Palmes, Designing the Minera Alumbrera Concentrator Circuit, Mining Engineering., Sept. 1998, pp. 31-37


