# Gravity Circuit Optimisation via Mathematical Modelling by Particle Size Classes

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## Abstract

Many factors affect the overall performance of a gravity circuit beyond that of the primary gravity recovery device. It is critical to examine the gravity circuit in its entirety in order to determine the dominant operating variables that affect overall performance. Knelson has developed a mathematical model which has been used to assist in the design of gravity circuits, and in particular, in making accurate predictions of plant scale gravity recovery.

More recently, inclusion of recovery by particle size class and additional data from various mine sites and research studies has made the model more robust. The model is now able to predict GRG (gravity-recoverable-gold) recoveries using various devices such as centrifugal concentrators, shaking tables, jigs and flash-flotation within the grinding circuit. The benefits derived by these recent advancements in modeling capability are two-fold; the first is as a tool to assist in circuit design and correct equipment selection and the second is as an analytical tool to help to evaluate and enhance the performance of existing gravity circuits.

## Introduction

Gravity concentration using centrifugal concentrators has gained wide popularity over the last 20 years, mainly due to the acceptance and widespread use of the Knelson Concentrator. The benefits of gravity recovery are now well understood, and generally well accepted by the industry. The fact that most mills will install gravity circuits when a reasonable amount of GRG is present in an ore bears witness to the acceptance of this technology. The increased use of gravity concentration in the grinding circuit has encouraged the demand for better understanding for the behaviour of gold in grinding circuits.

Gravity recovery in grinding circuits (usually in closed circuit ball mills) is the most common application for centrifugal concentrators. The simple fact that free gold and other heavy metals and minerals tends to build up in a circulating load make streams within the circulating load attractive for gravity recovery. The gravity recovery units are most commonly installed on a split stream from the cyclone underflow, mill discharge or cyclone feed.

The important factors, which influence gravity recovery of gold from grinding circuits, are:

1. The GRG content and the size distribution of the GRG – as measured using the GRG test
2. Circulating load of the grinding circuit – estimated from mill operating data
3. Split to gravity circuit – the amount of ore that is split from any of the streams within the grinding circuit.
4. Cyclone behaviour – gravity recovery relies on effective cyclone classification. The cyclone acts as an effective device to redirect a significant portion of the GRG back to the grinding circuit.
5. Gold room or refining approach – shaking tables and intensive cyanide leach systems are commonly employed for treating primary gravity concentrates hence the performance of these units have a significant effect on overall gravity gold recovery.

All of the factors listed above have been incorporated into a mathematical model to determine gold recovery. Additional inputs such as mill tonnage and grade provide information about the amount of gravity concentrate produced as well as grades of the concentrate and the cyclone overflow streams. The model can then be used as a basis for predicting gravity recovery for retrofit installations or as an auditing tool for existing gravity circuits. It can also provide design criteria data for greenfield installations.

## MODEL INPUTS

The mathematical model itself is built in MS Excel™ and uses the programs iterative solver function to arrive at the solution for grades and recoveries of the various streams. The inputs are based on data available from previous studies conducted by Laplante, AMIRA's P420B project and Knelson.

The important inputs are discussed in more detail in the following sections.

### Ore Characterization - The GRG Test

The GRG test measures the amenability of the gold to gravity recovery quantitatively. The GRG value is the theoretical recovery limit of gold by gravity concentration under ideal conditions. The results can be either reported as a bulk GRG value or as recovery by particle size class.

The GRG test itself consists of three sequential liberation and recovery stages using a lab scale Knelson Concentrator (the KC-MD3). The feed first stage requires the material to be crushed to a nominal 20 mesh. The next two stages are typically conducted at 45-60% passing 75 microns and 75-80% passing 75 microns. Progressive grinding (as opposed to testing only at final grind) limits smearing of coarse gold particles that may be present in the as-crushed sample. The test simulates the progressive liberation and recovery of gold normally achieved in grinding circuits and provides a size distribution of the GRG.

An example of a typical response from two GRG tests is shown in Figure 1. Note that both samples have a cumulative bulk GRG value of 70% but the distributions are different. This difference is important to note as it impacts the behaviour of the GRG within the circuit and ultimately gravity gold recovery.

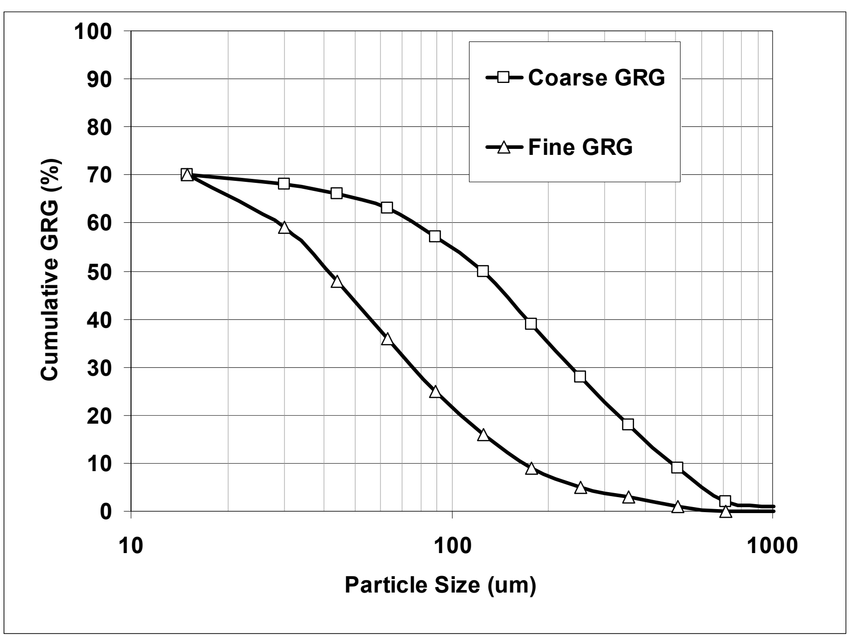


**Figure 1. Cumulative GRG recovery as a function of particle size.**

### Cyclone Behaviour

Cyclones, by their very nature, separate particles by density as well as by size. A small heavy particle tends to act like a larger light particle, thus gold tends to report to the cyclone underflow until it grinds to a size typically 2-3 times finer than that of the gangue. There is a large and measurable benefit to recovering the GRG before it grinds down to finer size classes, as smearing losses are minimized and loss of coarse GRG to the cyclone overflow by circuit upsets are minimized. It is generally impractical (and not necessary) to treat the entire circulating load thus only a portion needs to be treated for effective gravity recovery. The behaviour of gold in grinding circuits has been studied and reported by Laplante et al.

Since cyclones are responsible for retaining GRG within the grinding circuit, their performance is essential for effective gravity recovery. Figure 2 below provides examples of a poor and good cyclone performance for GRG. As can be seen, the partition curves indicate the GRG cuts at much finer particle size than the ore particles.

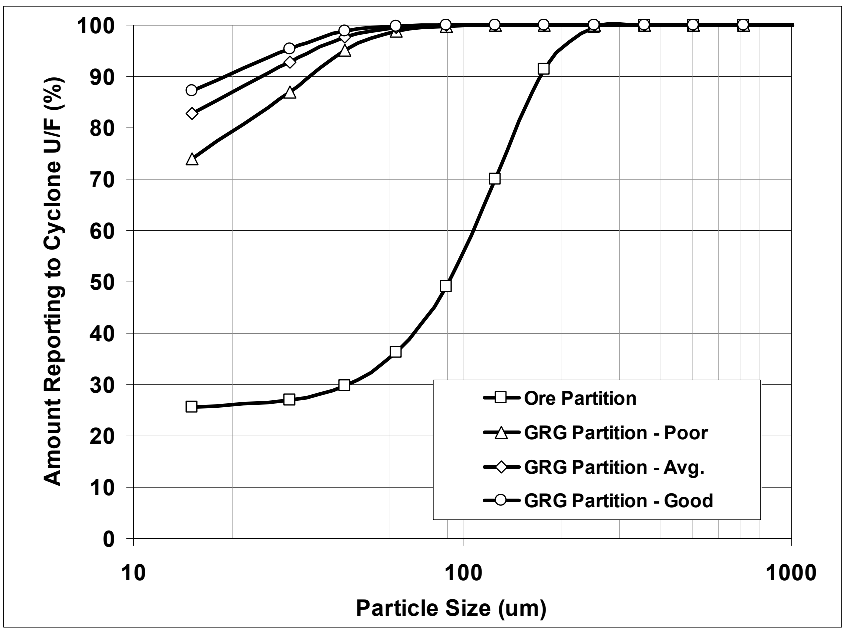


**Figure 2. Examples of partition curves for GRG relative to a typical ore curve. Note that the GRG partition curves are not derived from the ore partition curve shown.**

### Primary Gravity Recovery and Concentrate Upgrading

The response of the primary gravity concentration devices, such as the Knelson Concentrator, has been studied and reported by Laplante and AMIRA. This data is incorporated into the mathematical model.

The concentrate produced from primary units is usually upgraded using a shaking table although, more recently, intensive cyanide leaching of the concentrates has been gaining popularity. Additional data for upgrading units such as a shaking table and the Consep Acacia (intensive cyanide leach system) has been obtained from onsite pilot and full-scale test work.

The model allows for inputs based on newer or alternative data for any of these unit operations. Hence, the model works equally well for any primary and secondary gravity device as long as its recovery characteristics are known as a function of particle size.

No data is presented herein for the stage recoveries by particle size of the gravity device, as it considered confidential by the parties that have generated the data.

## SAMPLE MODEL INPUTS AND DISCUSSION

### Benefit of using recovery by particle size class approach.

Previous work with the model focused on using bulk values or un-weighted averages for the GRG value, cyclone performance and stage recoveries of the gravity concentration devices. This approach often under or over estimated the recoveries when the particle size of the gold was biased to the coarse or fine fractions. The results herein are presented comparing the simplistic method of using bulk values as opposed to incorporating particle size data into the model to elucidate the benefit of using the latter approach.

An example of an output from the model is shown in Figure 3. Gold recovery is plotted as a function of the fraction of the cyclone underflow treated by gravity concentration from a conventional milling circuit.

The first outcome to note is that the recovery rises very quickly within the first 20% of the cyclone underflow treated beyond which the curve begins to plateau steadily. This response is typical of these types of circuits.

The difference between using a bulk GRG value versus an approach that utilizes GRG by particle size provides a considerably different prediction of gold recovery. The coarse and fine GRG curves are based on the two GRG distributions shown in Figure 1. Hence, using a bulk value of the GRG can under or over estimate the GRG response. Note that the coarse and fine GRG, both of which have a value of 70%, provide a significantly different response. As expected, coarse GRG is recovered much faster and to a much higher absolute value than the fine GRG for equivalent amounts of ore treated.

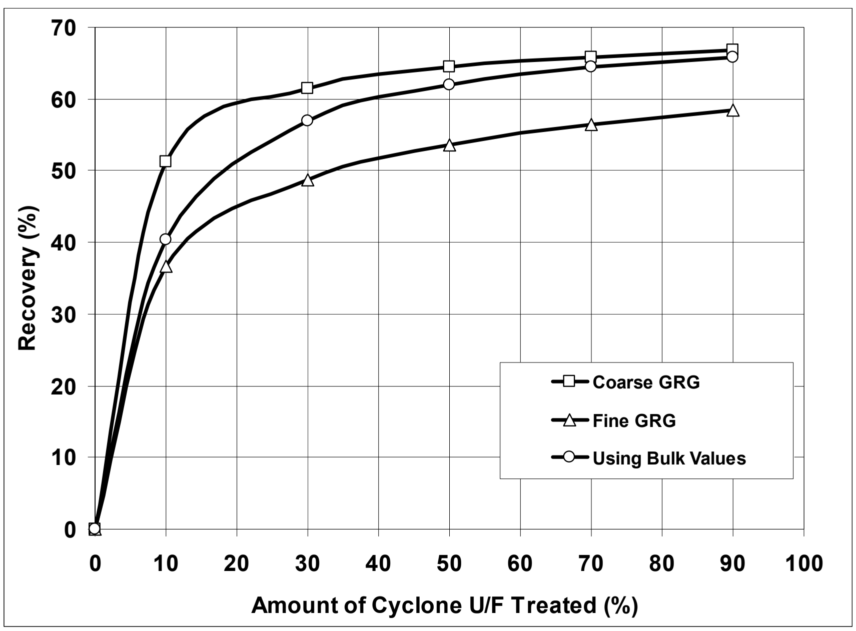


**Figure 3. Gold recovery as a function of amount of cyclone underflow treated. The total GRG value = 70%. The GRG distributions for fine and coarse GRG are shown in Figure 1 and average cyclone response from figure 2. No concentrate recovery device is used for this simulation (i.e. primary gravity recovery is considered to be final recovery).**

**Effect of Cyclone Performance**

A sensitivity analysis readily shows that the cyclones play an important role in gold recovery from grinding circuits. Poor or “lazy” cyclone partition curves or significant upsets in the cyclone feed can cause premature loss of gold to the overflow. A poor partition curve for the ore gives rise to a poor partition curve for gold and GRG. Recent work under AMIRA’s P420B project has shown that the ore partition curve can be used to predict the GRG partition curve.

Figure 4 below compares the relative effect of cyclone behaviour on a fine GRG sample. A comparison is also done for a bulk cyclone value of 98% (the probability of a GRG particle reporting to the cyclone underflow). As can be seen, using a bulk value overestimates recovery.

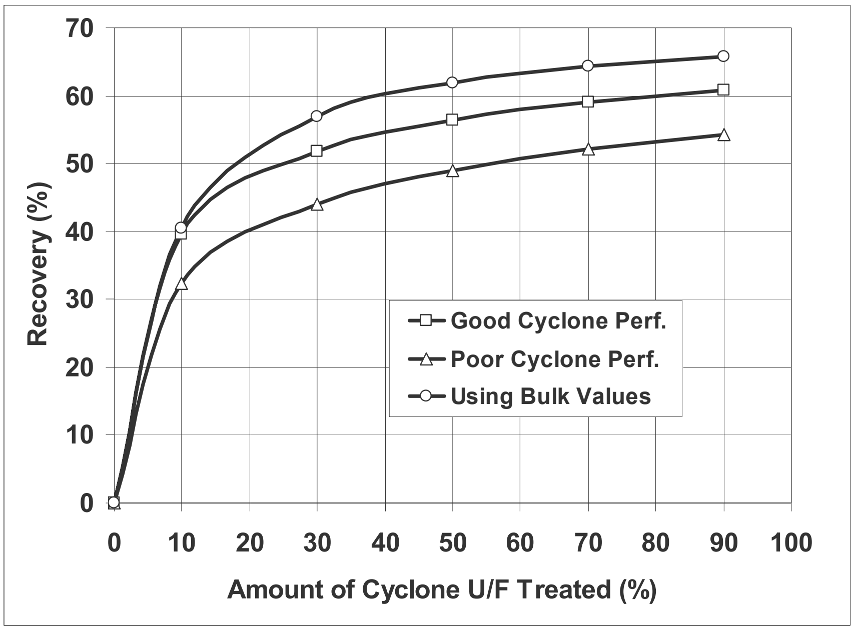


**Figure 4. Gold recovery as a function of amount of cyclone underflow treated. The total GRG value = 70%. The fine GRG distribution used for this scenario is shown in Figure 1 and average cyclone responses used are from figure 2. No secondary concentrate recovery device is used for this simulation (i.e. primary gravity recovery is considered to be final recovery).**

**Effect of Stage Recovery and Extreme Case Behaviour**

The stage recovery has only a small impact on gold recovery as can be seen in Figure 5. The effect of stage recovery is even less if the classification circuit is operating well by returning the GRG to the grinding circuit.

Figure 6 represents an extreme case where all of the inputs used are at either end of the response for an ore with 70% GRG. For example, upper curve represents a case where the GRG is coarse (from figure 1), cyclone efficiency (from figure 2) and stage recoveries are set at the high values. The lower curve utilizes the fine GRG values and the lower cyclone and stage recovery values.

The most important thing to note is that the same GRG value can produce extremely large differences in recovery based on differing particles size distributions, classification behaviour and stage recovery responses.

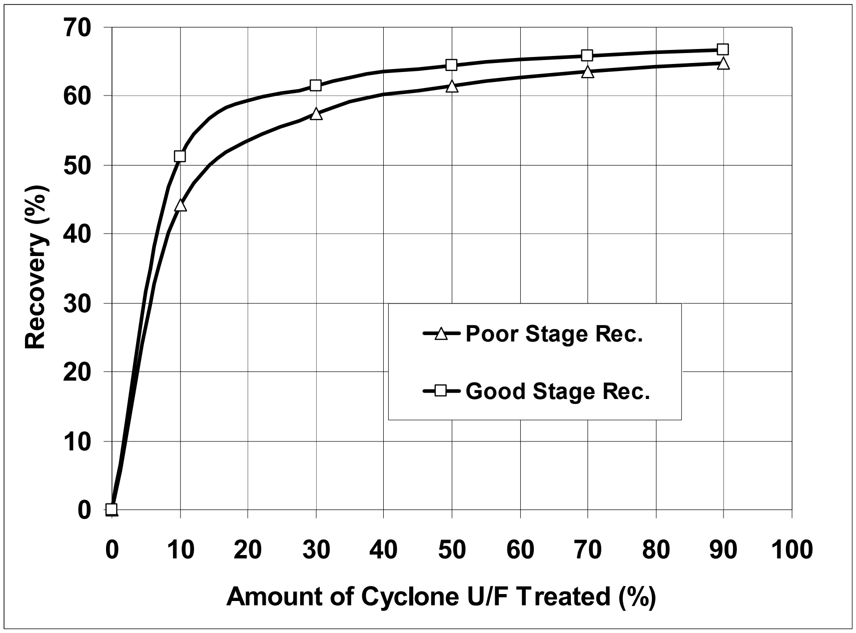


Figure 5. Gold recovery as a function of stage recovery for a coarse gold feed. (as per Figure 1) and the average cyclone responses from figure 2. No secondary concentrate recovery device is used for this simulation (i.e. primary gravity recovery is considered to be final recovery).

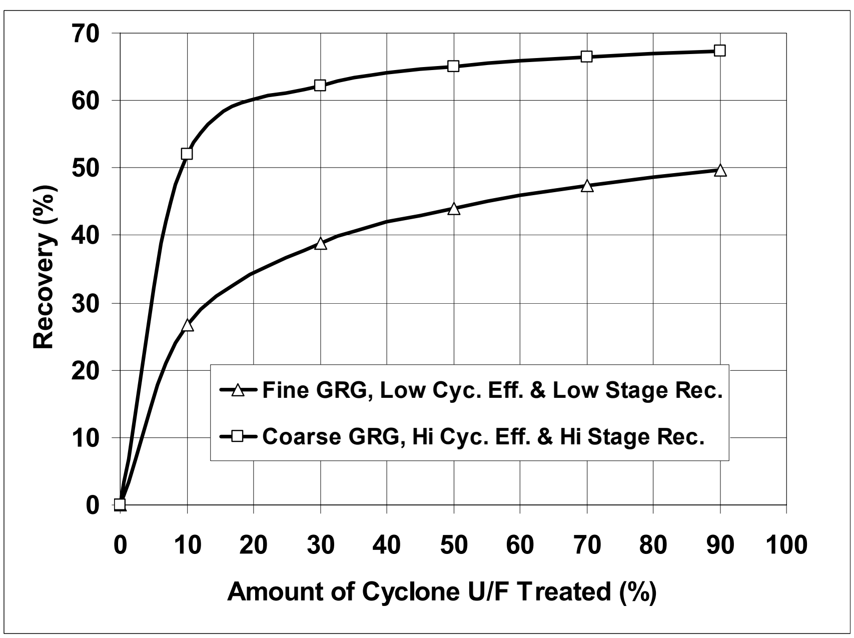


Figure 6. Gold recovery as a function of stage recovery for extreme cases of GRG size distribution, cyclone response and stage recovery.

**Effect of Concentrate Treatment Efficiency**

The most common method used for treating primary gravity concentrates from a Knelson is tabling. More recently, intensive cyanide leaching has been gaining popularity due to factors such as higher gold recovery, security and lower labour costs whereas gold recoveries using tables have been observed to vary widely and are highly dependent on operator experience and skill.

Figure 7 below compares the relative effects of using the various technologies. As can be seen, the intensive cyanide leach is far superior to using tables and lies on top of the ideal recovery line (not shown).

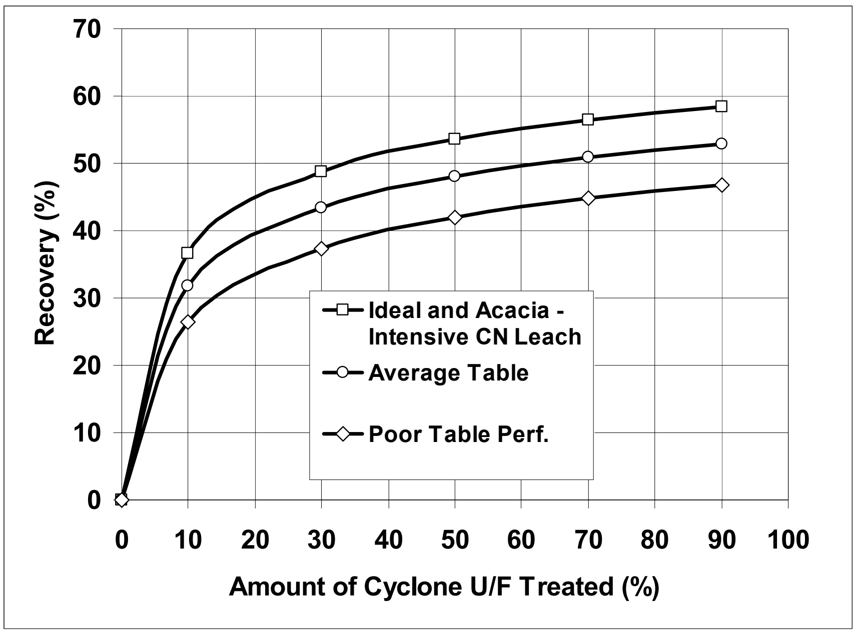


**Figure 7 Gold recovery as a function of stage recovery for fine gold with tabling or intensive cyanide leach of the Knelson concentrate. Note that the Acacia line lies on top of the ideal recovery line.**

## CONCLUSIONS

It has been demonstrated through mathematical modeling that using particle size data for predicting gravity gold recovery provides different results than using un-weighted average (bulk) values. Recent research has helped to establish a database of stage recoveries for primary and secondary gravity concentration equipment and cyclone performance as a function of particle size. Using this approach has helped to more accurately model circuits where gravity recovery is carried out within the grinding circuit and to improve operation of existing circuits.

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