EFFECT OF OPERATING VARIABLES IN KNELSON CONCENTRATORS: A PILOT-SCALE STUDY

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Abstract

Knelson concentrators are the most widely used semi-continuous centrifuge separators for the recovery of gold and platinum minerals by gravity methods. Bench scale characterization studies on these units provide information about the occurrence of gold in ore samples (e.g. gold particle size distribution, amount of gold recoverable by gravity) but not about the effect of operating variables for full-scale units such as top size of particle, feed rate, fluidization flow rate and rotation speed. Such work is not easily performed online on full-scale units owing to the inevitable variations in feed quality and to the impossibility of varying operating parameters systematically in the face of production requirements. To attack the problem, a pilot plant comprising a 12-in CD Knelson concentrator, a feed screen and tailing sump-pump arrangement was installed in the grinding-B circuit of Dome Mine, Porcupine Joint Venture (PJV), now Porcupine mine, Goldcorp Inc. Timmins, Ontario. The pilot plant received a bleed from the feed to the full-scale units. The pilot facility was extensively sampled in two campaigns. Fifteen tests were conducted in the first campaign and another sixteen in the second. In all 31 pilot tests, twenty six 30-minute recovery cycle tests, called "short tests" and five, 90-minute recovery cycle tests, dubbed "long tests", were conducted. Measuring recovery was the focus of the "short tests"; measuring the deterioration of recovery over time was the focus of the "long tests". The sampling protocols were designed accordingly.

Detailed metallurgical balances were made to analyze the effect of operating and design variables on the performance of 12-in pilot Knelson Concentrator as a step towards understanding full-size units and to study the mechanism of concentrate bed erosion. To gain some fundamental information about the recovery mechanism of the Knelson concentrator, percolation of dense particles in a gangue bed was investigated using a fluidized bed column in the gravitational field.

Metallurgical results indicate that operating conditions including feed rate, rotation velocity, fluidization water flow rates and top feed particle size have little impact on the shape of the recovery compared to feed size distribution. A particle size hypothesis was tested using relevant industrial Knelson concentrator data. The analysis showed that a relatively coarse feed would impact negatively on the recovery between 106 and 425 µm. On the other hand, it would make it easier to recover particles between 25 and 106 µm. A finer feed would have a bigger impact on recovery around 25 to 106 µm and would yield a GRG recovery that decreases monotonically with the decreasing of particle size. This would be linked to the natural resistance offered by the gangue particles to the percolation of gold particles, which is significant at a particle size where the gangue is most abundant. The flowing slurry may be compared to a dynamic screen, with openings roughly the order of magnitude of the dominant particle size. This finding is useful for the simulation of the Knelson units, which uses the typical recovery curve "decreasing recovery with decreasing particle size" for estimating gravity recovery and it was thought that the shape of the curve had no impact on the estimation. Now, with this finding, either the fine or coarse recovery curve will be used depending on the size distribution of the gravity circuit feed. For example, for a coarse target grind, the coarse curve could be used and, for a fine target grind, the fine curve could be used.

Settling tests in the gravitational field were conducted in coarse and fine gangue beds. For the coarse gangue bed, dense particles recovery is high for coarser fractions (600 to 150 µm) when the bed is partially fluidized, indicating that these particles intruded the gangue bed due to their mass and the high momentum. Whereas, for the fine bed, most of the dense mineral percolated through the fine gangue bed easily, indicating that the resistance of the gangue bed to the percolation of dense particles is a function of bed voidage, particle size and density of the gangue bed.

Résumé

Les concentrateurs Knelson sont les séparateurs centrifuges semi-continus les plus utilisés pour la récupération par gravité des minéraux d'or et de platine. Des études de caractérisation par banc d'essai sur ces unités fournissent de l'information sur l'occurrence d'or dans les échantillons de minerai (ex. la distribution de dimension des particules d'or, la quantité d'or récupérable par gravité) mais non sur l'effet des variables opérationnelles sur les unités à pleine échelle, comme la dimension supérieure, la vitesse d'alimentation, le débit de fluidisation et la vitesse de rotation. Ces travaux ne sont pas faciles à effectuer en ligne sur des unités à pleine échelle en raison des inévitables variations dans la qualité de l'alimentation et l'impossibilité de varier les paramètres d'opération à cause des contraintes de production. Pour résoudre le problème, une usine pilote comprenant un concentrateur Knelson avec un diamètre du cône (DC) de 12 pouces, un tamis d'alimentation et une pompe à résidus ont été installés sur le circuit de broyage-B de Dome Mine, Porcupine Joint Venture (PJV), maintenant Porcupine mine, Goldcorp Inc., Timmins, Ontario. L'usine pilote recevait une purge de l'alimentation des unités à pleine échelle. L'installation pilote a été échantillonnée de façon intensive lors de deux campagnes. Quinze tests ont été effectués durant la première campagne et seize autres dans la deuxième. En tout 31 tests, soit vingt-six tests ayant un cycle de récupération de 30 minutes (appelés « tests courts »), et cinq tests ayant un cycle de récupération de 90 minutes (appelés « tests longs ») ont été faits. Le focus était mis sur la mesure de la récupération pour les tests courts, le focus était mis sur la détérioration du temps de récupération pour tous les tests. Le protocole d'échantillonnage a été conçu conséquemment.

Des bilans métallurgiques détaillés ont été effectués pour analyser l'effet des variables opérationnelles et conceptuelles sur la performance du concentrateur pilote Knelson de 12 pouces dans le but d'approfondir la compréhension des unités pleine échelle et d'étudier le mécanisme d'érosion du lit de concentré. Pour obtenir des informations fondamentales à propos du mécanisme de récupération du concentrateur Knelson, la percolation de particules denses dans un lit de gangue a été investiguée en utilisant une colonne de lit fluidisée opérant dans le champ gravitationnel.

Les résultants métallurgiques indiquent que les conditions l'opération telles que la vitesse d'alimentation, la vélocité de rotation, le débit de l'eau de fluidisation et la dimension des particules grossières ont eu de l'impact sur la récupération comparativement à la distribution des dimensions de l'alimentation. Une hypothèse quant à la dimension des particules a été testée en utilisant les données industrielles reliées au concentrateur Knelson. L'analyse a montré qu'une alimentation relativement grossière aurait un impact négatif sur la récupération de particules entre 106 et 425 µm. D'un autre côté, elle faciliterait la récupération des particules entre 25 et 106 µm. Une alimentation plus fine aurait un plus grand impact sur la récupération de partie autour de 25 à 106 µm et apporterait une récupération par gravité de l'or (« GRG ») qui diminuerait de façon monotone avec la diminution de la dimension des particules. Ceci serait lié à la résistance naturelle des particules de gangue à la percolation des particules d'or, ce qui est significatif à une dimension de particules où la gangue est plus abondante. Le liquide chargé s'coulant peut être comparé à un tamis dynamique, avec des ouvertures environ de l'ordre de grandeur de la dimension dominante des particules. Cette découverte est utile à la simulation des unités Knelson, qu'utilise habituellement une courbe de récupération dans laquelle « la récupération diminue avec la diminution de la dimension des particules », pour permettre l'estimation de la récupération par gravité; il était industriel de penser que la forme de la courbe n'avait pas d'impact sur l'estimation. Avec cette découverte, dorénavant la courbe de récupération, fine ou grossière, sera utilisée en fonction de la distribution des dimensions de l'alimentation du circuit gravitationnel.

Des tests de décantation dans le champ gravitationnel ont été effectués dans des lits de gangue grossière ou fine. Pour les lits de gangue grossière, la récupération des particules dense est élevée pour les fractions grossières (600 à 150 µm) quand le lit est partiellement fluidisé indiquant que ces particules empiètent dans le lit de gangue à cause de leur masse et le grand dynamisme. Pour ce qui est du lit fin, la majorité du minéral dense percolait facilement à travers le lit indiquant que la résistance du lit de gangue à la percolation de particules denses dépend de la fraction vide du lit, de la dimension des particules et de la densité du lit de gangue.

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Nomenclature

GRG	gravity recoverable gold
LKC	Laboratory Knelson concentrator
KC	Knelson concentrator
KC CD	Knelson concentrator centre discharge
KC XD	Knelson concentrator extended duty
KC MD	Knelson concentrator manual discharge
GRPGM	gravity recoverable platinum group minerals
FC SB	Falcon concentrator SB
FC C	Falcon concentrator Continuous
g/t	grams per tonne
t/h	tonnes per hour
G	times of gravitational acceleration
kg/min	kilograms per minute
g/min	grams per minute
l/min	litres per minute
SAG	semi-autogenous grinding
PBM	population balance model
P_{80}	the particle size at which 80% of the mass passes
ω	angular velocity
Dp	particle diameter

ρ_s	particle density
ρ	fluid density
μ	viscosity of fluid
v	velocity of the particle along the tube wall (in equation 2.1)
ψ	non-sphericity coefficient of the particle (in equation 2.1)
φ	voidage fraction

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Chapter 1 Introduction

1.1 Gold gravity concentration

Concentration of gold by gravity method has been common since antiquity due to its simplicity, large processing capacity, low operating cost and most importantly, because it does not use any chemicals. Gold's high specific gravity (19.3 g/cm^3 when pure) compared to the typical low density gangue minerals (2.1 g/ cm^3 to 5.0 g/ cm^3) makes the concentration process by gravity methods attractive. However, properties such as particle shape, porosity and hydrophobicity can lower recovery (Spiller 1983, Burt, 1984). The main drawback of gravity processes is related to the recovery of fine gold (< 75 µm) and that of gold associated with sulfide minerals (Laplante and Shu, 1992). Advances in cyanidation and flotation processes led to the decline of gravity concentration. For example, in the 1980s about 20% of the South African gold was produced from gravity concentration whereas in the early 1990s, gravity recovery disappeared from most gold plants. Carbon adsorption gained widespread acceptance in the 1990s and, in a typical CIP plant, gravity concentration was not seen as beneficial for reasons of security, installation costs and because of difficult sampling and metallurgical accounting procedures. These drawbacks were combined with the perception that gravity did not increase overall recovery particularly when processing free milling ores (Laplante, 1987).

This decline prevailed for some time until the early 1980s when gravity concentration regained attention with the invention of centrifugal gravity concentrators (Knelson and Edwards, 1990, Knelson, 1992). Gold, because of its malleability (i.e. it does not readily break) and density, accumulates in the grinding circuit circulating load (Banisi, 1991). Due to this, a part of the ball mill discharge or cyclone underflow is typically processed by gravity to recover coarse gold prior to flotation and/or cyanidation. Users of gravity concentration maintain the following:

1- The earlier the gold is extracted, the sooner (relatively) it can be smelted, refined and sold, thus maximizing net smelter return (NSR);

2- Overall cyanidation plant recovery could be improved by extracting coarse gold prior to leaching where it may have insufficient contact for dissolution;

3- Overall flotation plant recoveries could be improved by removing gold that is too coarse to float;

4- The high gold circulating load in grinding circuits could be reduced to minimize gold accumulation, thus reducing the buildup and consequent flattening and overgrinding of the gold;

5- Low gravity plant installation costs (less than 3% of the total) are possible (Wells and Patel 1991).

It is clear that gravity cannot replace flotation or cyanidation, but it can reduce circuit size, reagent usage and their resulting environmental impacts. Centrifugal concentrators, particularly the Knelson concentrator, were established as the choice over the other gravity concentrators for the recovery of gold from grinding circuits thanks to their mechanical and operational simplicity, their ability to achieve good gold recoveries over a wide size range (2000-20 µm) and for the fact that they can be readily retrofitted in existing circuits.

1.2 Knelson concentrator

Knelson concentrators are the most widely used semi-continuous centrifugal gravity for recovering gold and platinum group minerals from grinding circuits. Patented by Byron Knelson (Patent: CA2271958, 1998) in Canada in the early 1980s, these machines received wide acceptance replacing non-centrifugal gravity concentrators from gold grinding circuits around the world. Initially developed for processing alluvial gold, these machines proved beneficial for hard rock and gold vein applications (Knelson and

Edwards, 1990; Suttill, 1990; Laplante et al., 1990; Poulter et al., 1994; Meza et al., 1994; Darton et al., 1995; Cloutt, 1995; Hart et al., 1995).

In most applications, Knelson concentrator (KC) uses a centrifugal force of 60 Gs to recover gold particles as fine as 20 µm. The separation mechanism is the same for all models. It is based on the difference in the centrifugal force applied on gold and associated gangue minerals and the fluidization of the concentrate in the riffles (Figure 1). It combines the advantages of a simple structure, small footprint, high capacity, wide particle size range recoverability and most importantly, the ability to yield very high enrichment ratios up to (1000:1) in a single stage.

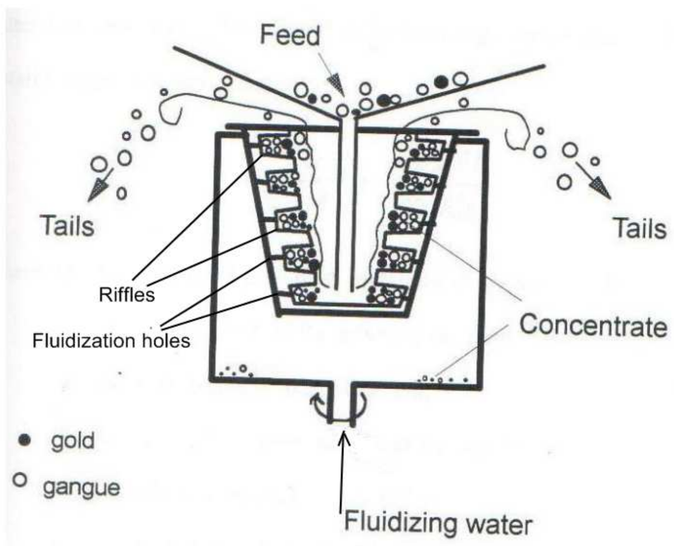

Figure 1: Separation mechanism in a KC

Most of the research on Knelson concentrators was carried out at McGill University. It includes the characterization of gold ore types (Laplante, 1993; Woodcock and Laplante, 1993; Laplante et al., 1995; Laplante et al., 1997), evaluation of plant performance (Putz et al., 1993; Laplante et al., 1996b; Zhang, 1998), fundamentals of semi-batch centrifuge operation (Buonvino, 1993; Huang, 1996; Ling, 1998 and Xiao, 1998) and the study of concentration mechanisms with a laboratory Knelson concentrator (Laplante and Shu, 1992, Laplante et al.,1994, 1995, 1996, 1996a, 1996b).

Despite these works, no comprehensive study of the impact of operating variables on KC performance reflecting realistic full-scale operating practice have been produced. Laboratory-scale tests or bench-scale exercises cannot meet this need and, as Knelson-based gravity circuits are typically difficult to sample due to high volumetric flow rates and operating conditions that cannot be varied systematically in the face of production constraints, full-scale work is necessarily limited.

The present research aims to remedy this deficiency by performing a comprehensive study of the effect of operating variables on a pilot Knelson (KC CD12) concentrator installed in a gold grinding circuit parallel to the operating Knelson concentrators. The study aims to help better understanding of the effect of operating variables in order to improve the performance of full-scale Knelson concentrators.

1.3 Background of research

Gravity recoverable gold (GRG) refers to the portion of gold in ores or mill streams that can be recovered by gravity into a small concentrate mass (typically less than 1% of the feed). GRG includes gold that is fully liberated, as well as gold that is locked in high density composite particles that report to the concentrate. Photographic evidence shows that the coarser gold fractions (> 300 µm) recovered in concentrates are not fully liberated. On the other hand, fine fully liberated gold at < 20 µm is not recovered by gravity because of mass and shape effects.

The gold gravity research group at McGill University developed a methodology to model the recovery of gold from the circulating load of grinding circuits. It was applied mostly to the gravity recovery of gold. The methodology relies on the following three elements (Laplante and Staunton, 2005):

- A test to characterize gravity recoverable gold (GRG);
- A description of the behavior of GRG particles in grinding and classification units;
- A measure of the performance of gravity recovery units.

The test to characterize the GRG content of gold ores (Laplante, Woodcock and Huang 2000) is performed with a laboratory Knelson concentrator (LKC). The methodology was used for characterizing more than 200 ore samples at McGill University (Huang and Koppalkar, 2007). Research on the second element, prediction of the behavior of GRG in cyclones and grinding, was carried out under the auspices of AMIRA P420B (Laplante and Staunton, 2005). For the third element, GRG unit characterization, the most commonly used gravity recovery unit is the Knelson concentrator (KC), and three types of characterization methods are available (Laplante, 2001).

Under the first type of characterization, an extensive laboratory database was generated both with synthetic (Huang, 1996) and natural ores (Laplante, Shu and Marois 1996). Although this database proved beneficial in identifying trends on the impact of operating variables, it failed to predict full-scale unit recovery largely because the feed rate per concentrating surface area, or specific surface area, is typically 10 to 20 times higher in full-scale units than for laboratory test work. Attempts to achieve typical industrial specific feed rates at laboratory-scale meet with both the geometric constraints of feeding large quantities of material in a small concentration volume and the practical constraints of feeding large masses of material to achieve a feed rate and recovery cycle time similar to that an industrial unit. The research on laboratory-scale Knelson concentrators, demonstrated that it is impractical to attempt to mimic the performance of the full-scale units. For example, a 30-inch central discharge Knelson concentrator (KC CD30) typically treats 60 t/h over a 1-hour recovery cycle, achieving a recovery of 25 to 35 kg of concentrate. For a 3-inch laboratory Knelson concentrator (LKC) to achieve the same yield at the same specific feed rate (defined as the feed rate divided by the concentrating surface area), a total feed mass of 200 kg and a feed rate of 10 kg/min are needed. Not only is the feed mass impractically large, the downcomer geometry of the LKC precludes such a high feed rate.

In the second type of characterization a database on full-scale Knelson concentrators was developed at McGill University by careful sampling of operating Knelson concentrator. The collection of samples over a full recovery cycle typically includes the sampling of the feed and tailings streams during the recovery cycle and the collection of all or part of the concentrate at the end of the cycle time. The feed and tailings samples are processed with the GRG protocol to estimate their GRG content (Woodcock and Laplante, 1993; Laplante and Shu, 1992) from which an overall gold and GRG recovery is calculated. The concentrate data is then used to mass balance each size fraction for gold and GRG to estimate recovery by size. This approach yielded useful data and has identified clear size-by-size GRG relationships. However, it suffered from drawbacks such as the uncertainty associated with the estimate of weight recovery or yield. Although this approach makes it possible to estimate GRG recovery accurately for a given set of operating conditions, it cannot be used to identify the effect of operating variables such as feed rate, feed top size, fluidization flow, length of recovery cycle, source of feed for the unit or feed percent solids.

The third type of characterization uses a pilot centrifuge unit or a small plant scale unit, for which feed rate can be measured accurately, all concentrate can be recovered to estimate yield and feed as well as tailings flows can be measured. It is this type of unit characterization that is pursued in this research.

1.4 Objectives of research

The main objective is to generate detailed and accurate GRG metallurgical balances to measure the performance of a pilot Knelson concentrator (KC CD12) as a step towards understanding full-size units. The study aimed at understanding the following:

1- The effect of operating variables on concentrator performance such as concentrator feed rate and rotation velocity;
2- The effect of feed particle size and feed rate on optimum fluidization water flow;
3- To determine how to maximize fine GRG recovery;
4- To identify the role of feed percent solids on concentrator performance;
5- To determine what the maximum concentrator recovery cycle time is.

So far, comprehensive data on the effect of full set of operating parameters on full-scale Knelson units is limited and many are available as “audits” for a typical set of operating parameters. There is one data set covering whole range of operating conditions, published on a KC XD20 (Charest, 2001). The test work on the KC XD20 identified the effect of rotation velocity and fluidization flow on GRG recovery. However, the high feed rate made impossible to change the nature of the feed, which was much finer than typical centrifuge unit feeds. Nevertheless, this exercise demonstrated the utility of operating a Knelson unit under controlled conditions. It is this type of concentrator unit characterization that was taken up in this research. In support, gravitational settling tests were also carried out on binary mineral mixtures tungsten (surrogate for gold) and silica to understand separation mechanisms in a Knelson concentrator because of the obvious similarities between gravitational and centrifugal settling.

1.5 Thesis structure

The thesis comprises seven chapters. Chapter 2 provides a review of the literature on various centrifugal gravity concentrators including the Knelson concentrator. Chapter 3 reports experimental design of the pilot tests conducted mainly in two sampling campaigns and presents metallurgical results and discussion of the test work. Chapter 4 presents the detailed metallurgical results and analysis of the fifteen pilot tests conducted during campaign 1. The metallurgical results of another sixteen tests at high feed rates, coarse top size and high percent solids conduced in campaign 2 are also discussed. In Chapter 4, test work of all thirty one pilot tests with metallurgical results in a global perspective is discussed along with GRG recovery modeling and detailed analysis of the effect of operating variables. In Chapter 5, test work on gravitational settling and its correlation to centrifugal settling is discussed. In Chapter 6, general conclusions based on the pilot tests are presented and claims to original knowledge and suggestions for future work are also included.

Chapter 2 Literature review

2.1 Gravity concentration

Gravity concentration, the oldest form of mineral processing operation, remained as a primary tool along with hand picking for most of the last 2000 years. Because of its simplicity, this ancient inexpensive and environmentally-friendly process not only survived but continued to play an important role in modern mineral processing plants. Gravity concentration was the process of choice in small and remote artisan plants and it is literally used for the concentration of minerals from A (Andelusite) to *Z* (Zircon) (Burt, 1999).

Sluices are the simplest form of gravity concentrator. These separators have a sloped design with a narrowing sluice deck. Separation takes place by the settling of fine heavies to the bottom of the flowing film and the movement of coarse light minerals to the top. The main drawback of sluices is their low capacity per unit width, which is less than 10 t/h/meter.

Reichert cone is a high capacity sluice capable of processing up to 350 t/h (Abols and Grady, 2005). These machines separate at high pulp densities (60-65% solids by weight). However, due to the low upgrading ratios, typically in the range of 3 to 1, their concentrates need further cleaning. Headroom is also a problem for these machines in circulating load applications.

Spirals are film concentrators where slurry flows down a helical spiral surface and particles of different specific gravities stratify vertically and horizontally. The denser particles concentrate in a band along the inner side of the stream and are split off and discharged at different points of the path. Typical feed size is between 3 mm to 75 µm. The main problem of the use of spirals in circulating load application is the requirement of low feed density (15-45 % solids). As a result only a part of circulating load can be treated yielding poor performance. The main limitation of spirals is that particles below 105 μm are not efficiently recovered.

Jigging is one of the oldest gravity separation methods used to recover gold from grinding circuits. Separation of minerals of different specific gravity by jigging occurs in a fluidized bed by a pulsating current of water, which produces stratification. The purpose of jigging is to dilate the bed of minerals and control the penetration of heavier, smaller particles into the interstices of the bed and separate the stratified layers into two discrete products (Burt, 1984). The main drawbacks are high water consumption, low availability (high down time), high operator dependence, low upgradeability and poor security, especially for gold applications.

The Wilfley table is a shaking table that has been used for over 100 years. Deister and Holman tables are the other commercial shaking tables. Due to low capacity, shaking tables are typically used for cleaning duties or secondary upgrading of gravity concentrates produced from centrifugal gravity concentrators, jigs or spirals typically yielding smeltable concentrates. Performance ranges from recoveries ~80% with conventional tables to mid 90% with a Gemeni table. The main drawbacks of these machines are high operator dependency and poor security in gold applications.

2.2 Centrifugal gravity concentrators

Centrifugal concentrators, also referred to as enhanced gravity concentrators, employ centrifugal force to improve the settling rate of particles. This approach has been applied for many years in size classification by hydrocyclones and for heavy media separation. Patents were granted on centrifugal concentrators as early as 1920s. There are at least seven different types of centrifugal gravity separators commercially available and new types are still being developed. The better-known separators are: the Knudsen bowl, Knelson, Falcon SB, Falcon C, Kelsey Jig and the Mozley multigravity separator. The Knudsen, Knelson, Falcon SB and Falcon C machines are of the same generic type.

Except for the Knudsen, all other concentrators are available in different sizes and higher capacities. These machines are best suited for feeds containing a small percentage of high density material. They can be used either for roughing, scavenging or cleaning. Generally, a smaller machine would be used for cleaning on a batch scale. Their main application is for the recovery of gold, but they have potential to recover any mineral that has significantly higher density than the bulk of the feed.

Two centrifugal concentrators of Canadian origin, the Knelson Concentrator and the Falcon Concentrator, have gained widespread application. They are mainly grouped as semi-continuous and continuous types. Conventional gravity separation devices need a minimum relative density differential of at least one between the light and heavy phases for an effective separation whereas for the centrifugal machines, the minimum required density difference is even low. However, the bigger the density differences the better for the separation.

Knelson continuous variable discharge (CVD), Falcon C, Kelsey Jig and Mozley Multi-Gravity Separator (MGS) are continuous centrifugal gravity separators suitable for the recovery of minerals at finer sizes. The Knelson continuous variable discharge (CVD) concentrator has a solenoid valve mechanism for continuous extraction of concentrate from the riffles (McLeavey et al., 2001). Knelson CVD can process up to 300 t/h, recovering particles as fine as 25 µm. Falcon C concentrators (C for continuous) have similar extraction manifolds for handling concentrates (Honaker et al., 1996a). These units have been used on pilot scale on different coals in the United States (Luttrel et al., 1995; Honaker et al., 1996b). Falcon Concentrators claim that Falcon C machines are capable of processing 100 t/h of solids, recovering particles as fine as 10 µm. Continuous machines like Knelson CVDs have been used in many gold plants targeting the recovery of gold in sulphides. However, the use of these units for preconcentrating gold from grinding circuits replacing semi-continuous concentrators is yet to be seen.

The Kelsey Jig can handle feeds up to 100 tph for recovering particles as fine as 20 µm. The Kelsey Jig is limited by its capacity to discharge concentrate and is best suited for feeds containing small amount of heavies (up to 15 % maximum). Recovery of ragging, cost of ragging pre-screening and feed preparations are the drawbacks of this unit (Malvik et al., 1997). With the development of synthetic ragging materials, wider applications are found for the Kelsey Jig. The Mozley gravity separator (MGS) can generate centrifugal forces ranging from 8 to 22 Gs (Cordingley, 1997) and handle throughputs up to 5 t/h with a particle size range between 75 and 5 µm (Chan et al., 1991). Burt commented that the MGS is capable of recovering ultra fine particles effectively down to 10 µm (Burt et al., 1995). For the MGS, the rotation speed and inclination angle of the drums need to be adjusted to suit the ore. The main drawback is its low capacity. However, the new twin drum design is capable of processing 25 t/h and is claimed to effectively recover particles ranging from 200 µm to 2 µm.

2.2.3 Force balance in centrifugal concentrators

The earliest attempt to model centrifugal separation was made by Ferrara (1960). Performing a series of tests on pure galena and limestone, Ferrara derived an equation for a spherical particle under viscous conditions as follows:

$$\frac{4}{3}\pi\left(\frac{D_p}{2}\right)^3 D_p \frac{dv}{dt} = -\frac{4}{3}\pi\left(\frac{D_p}{2}\right)^3 (\rho_s - \rho)\psi\omega^2\left(r_1 - \frac{D_p}{2}\right) - 18k\mu\frac{1}{r_1^4}Q\left(\frac{D_p}{2}\right)^3 + 24k\mu\frac{1}{r_1^3}Q\left(\frac{D_p}{2}\right)^2 - 6\pi k\mu v\left(\frac{D_p}{2}\right) \quad (2.1)$$

Where r_1 is the inside radius of the tube; ω is its angular velocity, D_p is the particle diameter, ρ_s and ρ are the densities of the particle and the fluid. ψ is the non-sphericity coefficient of the particle, μ is the viscosity of the fluid and Q is the flow of fluid in the tube, v is the velocity of the particle along the tube wall and k is the coefficient of non-sphericity of the particle. On the right side of the equation 2.1, the first term represents the frictional force between the particle and tube wall, the second, third and fourth terms express the thrust of the fluid. Equation 2.1 is based on Gaudin's (1939) analysis of particle motion in a flowing film concentrator. Ferrara's analysis shows that applying conventional fluid mechanical analysis; the optimum conditions for the separation of different minerals in a centrifugal separator can be estimated.

The centrifugal separation of minerals is complex, wherein all particles are subjected to forces including centrifugal, drag, buoyancy and interparticle collision. Particle separation mainly takes place during the radial movement. The radial movement of a particle in a Knelson concentrator may be divided into centrifugal settling and percolation. Based on Newton's second law, the movement of a spherical particle in a fluid under the action of centrifugal field and the forces acting on settling can be incorporated in (Kelly and Spottiswood 1982):

$$F_x - F_d - F_b = M\left(\frac{dv}{dt}\right) \tag{2.2}$$

where F_x is the centrifugal force, F_d is the drag force, F_b is the buoyancy force, M is the mass of the particle and dv/dt is the resulting acceleration of the particle.

The terms of equation 2.2 can be expressed in a centrifugal field as follows.
The external centrifugal force:

$$F_x = \left(\frac{\pi}{6}\right) d^3 \rho_s r \omega^2 \tag{2.3}$$

where r is the radial position of the particle of size d, ρ_s its specific gravity and ω the angular velocity.
According to the Stokes sphere-drag formula, the drag force can be:

$$F_d = 3\pi\mu d\left(\frac{dr}{dt}\right) \tag{2.4}$$

where μ is the viscosity of the water and dr/dt is the instantaneous radial velocity of the particle.

The buoyancy force in a centrifugal filed is given by:

$$F_b = (\frac{\pi}{6}) d^3 \rho r \omega^2 \tag{2.5}$$

where ρ is the density of water.

The inertial term on the right hand side of the equation 2.2:

$$M \ (\frac{dv}{dt}) = (\frac{\pi}{6}) d^3 \rho_s \ (\frac{d^2 r}{dt^2}) \tag{2.6}$$

Substituting equations 2.3, 2.4, 2.5 and 2.6 in equation 2.2, one can write the equation of motion of a spherical particle settling radially in the Knelson concentrator as:

$$(\frac{\pi}{6}) d^3 (\rho_s - \rho) r \omega^2 - 3\pi\mu d \ (\frac{dr}{dt}) \ = (\frac{\pi}{6}) d^3 \rho_s (\frac{d^2 r}{dt^2}) \tag{2.7}$$

The inertial term on the right hand side of equation (2.7) can be neglected or when the instantaneous velocity is close to the terminal settling velocity, the magnitude of the instantaneous velocity (dr/dt) will be:

$$\frac{dr}{dt} = \frac{d^2 (\rho_s - \rho) r \omega^2}{18\mu} \tag{2.8}$$

$$= \frac{d^2(\rho_s - \rho)g}{18\mu}\frac{r\omega^2}{g} = v_g \frac{r\omega^2}{g} \quad (2.9)$$

where r is the radial position of a particle, dr/dt is its instantaneous velocity and v_g is the terminal settling velocity of the same particle in the gravitational field. Thus the instantaneous velocity (dr/dt) in a centrifugal field is equal to the terminal settling velocity v_g in gravitational field multiplied by a factor $r\omega^2/g$ (Coulson and Richardson, 1990). The relation between the centrifugal settling and gravitational settling can be expressed as:

$$v = Gv_g \quad (2.10)$$

where v_g is the settling velocity of a particle under gravitational field and G is the relative centrifugal force, defined as the ratio of centrifugal force and gravitational force. The analysis is valid only for the Stokes region.

Through a detailed analysis, Hsu (1981) proposed the following correlation for the terminal velocity under centrifugal force and gravitational force:

$$v = G^{1/3}v_g \quad 0.4 < Re < 500 \quad (2.11)$$

$$v = G^{1/2}v_g \quad 500 < Re < 2 \times 10^5 \quad (2.12)$$

where G is the relative centrifugal force, as in equation (2.1). Comparing equations (2.10), (2.11) and (2.12), it can be seen that the centrifugal effect becomes more dominant over the particle settling velocity as the particle size becomes smaller. This is illustrated in Figure 2.

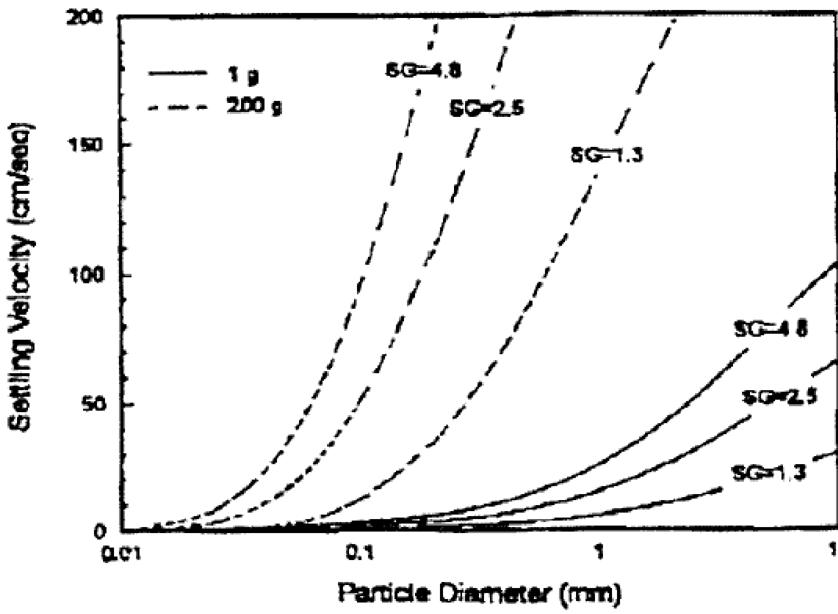

Figure 2: Effect of centrifugal force on particle settling velocities for various accelerations of 1 and 200 Gs and particle specific gravities SG (Luttrell et al., 1995)

Figure 2 shows the theoretical settling velocities of spherical particles of coal, shale and pyrite with specific gravities of 1.3, 2.5 and 4.8 respectively, as a function of acceleration. It can be seen that the separation of particles of coal and pyrite of less than 1 mm may not be possible under 1 G due to the minimal difference in their relative settling velocities, even though there is a substantial difference in their specific gravities. However, the difference in their settling velocities is greatly enhanced by a centrifugal gravitational field of 200 G even for particles less than 0.1 mm (Majumder, 2002).

Most of the published literature on centrifugal separation describe the settling behavior of a single particle in the flowing fluid utilizing expressions for fluid drag force that consider the motion of a single particle in isolation. However, in mineral processing all the separators operate at high particle volume fraction in slurry. Therefore, if the principle of centrifugation is applied for the separation of fine particles, it becomes imperative to consider the effect of particle interactions.

2.2.4 Particle percolation in the gravitational field

For dry and cohesionless particles, Bridgwater and co-workers (Bridgwater et al., 1983) have defined interparticle percolation as the drainage of one species through a particle array under shear. When strain is applied to an array of particles, relative particle movement takes place and is referred to as strain-induced percolation. Particles smaller than the bed are normally prevented from entering by the underlying particles. These underlying particles are shuffled with respect to each other due to the strain applied. Eventually the movement of large particles yields space for small particles to enter, or percolate. On the other hand, the motion of large particles through an array of small particles is called particle migration.

For bulk materials immersed in a fluid, Bridgwater et al (1983) proposed a relation for the percolation velocity, u, as,

$$\frac{u}{\omega d_b} = f\left\{\frac{d_b\,\omega^2}{g}\ ,\ \frac{d_p^{3/2}\,g^{1/2}\,(\rho_p - \rho_l)}{\mu}\right\} \tag{2.13}$$

where d_b is the bed particle diameter, d_p is the percolating particle diameter, ω is the rate of strain, ρ_p the percolating particle density, ρ_l the fluid density and μ the fluid viscosity. The significance of the two dimensionless groups on the right hand side of equation (2.13) is as follows:

1. $d_b\ \omega^2 / g$ is a measure of the ratio of the time for a particle to fall through a gap to the life time of the gap.
2. $\left[\frac{d_p^{3/2}\,g^{1/2}\,(\rho_p - \rho_l)}{\mu}\right]$ is the ratio of the net gravitational force to the viscous force acting on the percolating particle.

Table 1 shows the dimensionless percolation velocity (absolute velocity =u) of particles of diameter d_p in a media of particles of diameter d_b under a shear ω.

Table 1: Percolation characteristics of cuboid particles (Bridgewater, Cook and Drahun, 1983)

Material	Density (g/cm^3)	Dimensions (mm)	$u/\omega d_b$	$D_z/\omega d_b^2$	Pe_y
Acrylic Resin	1.19	8 x 8 x 4	0.87	0.042	2.4
Brass	8.37	8 x 4 x 4	1.43	0.084	1.3
Brass	8.37	8 x 8 x 2	2.18	0.140	1.6

The authors found that the dimensionless percolation velocity varied with the particle diameter ratio d_p/d_b and hence the percolating velocity of the smaller particle was higher than that of a larger particle under the same bed conditions. Table 1 also shows that the particle shape has significant effect on both percolation velocity and dispersion coefficient. What is more surprising is that the effect of density is limited (increase in density from 1 to 8 results in only a two-fold increase in percolation velocity). Percolation is also referred to as interstitial trickling. Consolidation trickling or interstitial trickling is one of the three mechanisms responsible for separation in jigging processes (Gaudin, 1939). Separation takes place at the end of pulse stroke when the jig bed begins to compact and larger particles interlock. Under the influence of fluid drag and gravity, smaller particles continue to move downwards through the interstices of larger ones, thus completing the interstitial process. Despite its complexity, Burt (1984) has shown that the maximum size of a particle d_p, that can pass or percolate between four equal equisized light spheres of diameter D_p can be estimated as:

$$D_p' = (2d_p^{\ 2})^{0.5} - d_p = 0.41d_p \qquad (2.14)$$

The separation mechanism in centrifugal concentrators involves interstitial trickling. The literature on interstitial trickling in a centrifugal field is limited, compared to interstitial trickling in the gravitation field. In view of the similarities, the knowledge from gravitational trickling will be useful in understanding and interpreting the trickling process in centrifugal concentrators.

2.2.5 Particle percolation in the centrifugal field

In Knelson concentrators, the combined action of fluidization water, centrifugal force and a shear-induced dispersive force caused by the upward moving slurry (Bagnold 1954) creates interstitial trickling that can be compared to percolation. The main forces acting on particles inside the Knelson bowl are centrifugal and drag as shown in Figure 3

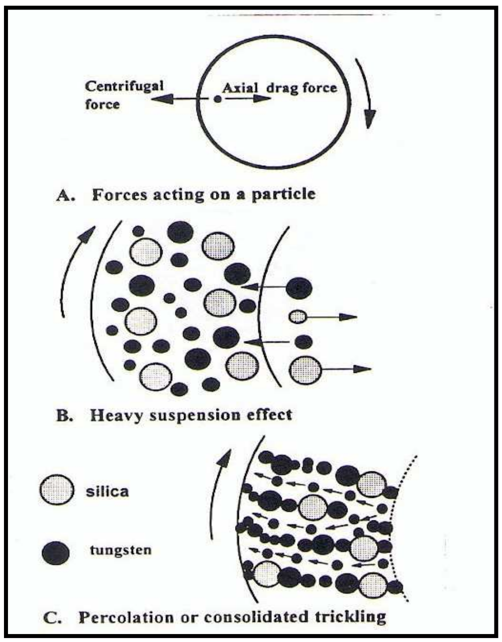

Figure 3: The mechanism of concentration in a KC bowl (Huang, 1996)

Fluidization water that enters tangentially, countercurrent to bowl rotation, penetrates the voids between particles and channels the bed predominantly along the paths of the fluidization water streams. Hence, there is little or no mass transfer between the solids already recovered in the inner portion of the rings and the material subsequently recovered.

Thus, the inner portions of the rings retain the coarse fractions. The gold grade of this material could be lower than the feed (Huang, 1996). At a constant rotation, particles with higher terminal velocity settle faster than the ones with lower terminal velocities. Capture of both coarse gangue and fine gold particles in a KC bowl cannot be explained by terminal settling velocity alone. This phenomenon is explained by consolidation trickling or percolation. Consolidated trickling is normally associated with a short phase (in the jigging cycle), but can be sustained over a longer periods of time if the bed of coarser particles is dilated, as in the case of Knelson, by the combined action of fluidizing water and a shear-induced dispersive force created by the upward moving slurry (Bagnold, 1954; Holtham, 1992).

Ling (1998) analyzed ring–by-ring recoveries and showed that the fast percolating (coarser) gold particles report to the lowest rings whereas most other size classes are recovered in the intermediate rings. Fine gold particles reported to the top most ring. Huang (1996) conducted studies on the distribution of material in the Knelson rings by using a vertically sectionable bowl. The photographs of the concentrate cakes recovered from each ring demonstrated that most of the denser phases were recovered on the surface of the concentrate bed due to partial fluidization. He concluded that the separation of target particles from gangue took place at the surface of the rings and depended mainly on the competing forces, on the acceleration of the mineral (during consolidation trickling) and the high density of the separation zone.

For the Falcon concentrator model B, Buonvino (1993) proposed two different recovery mechanisms: coarse particles are captured by burying themselves in the concentrate bed and the fine particles are captured by lodging themselves between the interstices on the surface of the bed, hence these two mechanisms can be regarded as particle migration and percolation and take place in a two step process (Laplante et al., 1994). He also suggested that the first step of migration and percolation is a function of feed rate and the second step of capture of dense particles in the concentrate bed is unaffected by the feed rate.

2.3 Knelson CD/XD concentrator

The Knelson CD or XD concentrator is a semi-continuous centrifuge machine designed to recover low-grade high density particles from associated gangue minerals by operating at high accelerations of 60 to 180 Gs (most units are operated at 60 Gs). These machines slowly replaced jigs, spirals and cones in plants around the world and thus established themselves as the workhorse for preconcentrating gold from grinding circuits. The operating mechanism of all models of Knelson concentrator is the same. It consists of a conical riffled bowl fitted concentrically in a cylindrical stainless steel outer bowl. Feed slurry is introduced by gravity to the bottom of the bowl through a downcomer. As soon as the slurry hits the bottom of the bowl, it is propelled to the periphery of the spinning bowl. Clear water at high pressure is injected tangentially into the fluidization holes (as shown in Figure 1); counter current to the rotation of the bowl, prevents compaction creating a fluidized concentrate bed (Harris, 1984). The heavies acted upon by centrifugal force report to the riffles as concentrate and the lighter gangue minerals are transported to the outer rim by the upward flow of slurry as tailings as shown in Figure 4. The water injected does not fully fluidize the material in the grooves themselves but controls the material that flows on top of this compacted bed and indeed, the slurry flow itself (Huang, 1996). The water controls the growth of this bed until the end of the recovery cycle when the machine is stopped and the concentrate automatically removed by slowing down rotation and purging the grooves with two flushes of wash water, a process that takes from 1 to 2 minutes. The concentrate drops to the bottom of the bowl and is evacuated via a Y-shaped tubing at the centre of the bowl (hence the CD brand, for central discharge) as shown in Figure 4. The XD model (for extended duty) is a more robust (stainless steel wetted parts) unit with the same geometry as the CD. The CD and XD models are available at diameters varying between 10 inches and 70 inches, processing up to 1000 t/h for the XD70 unit. For the lab and pilot scale units (MD3 to MD30), the concentrate is manually discharged at the end of the test, hence the MD denomination.

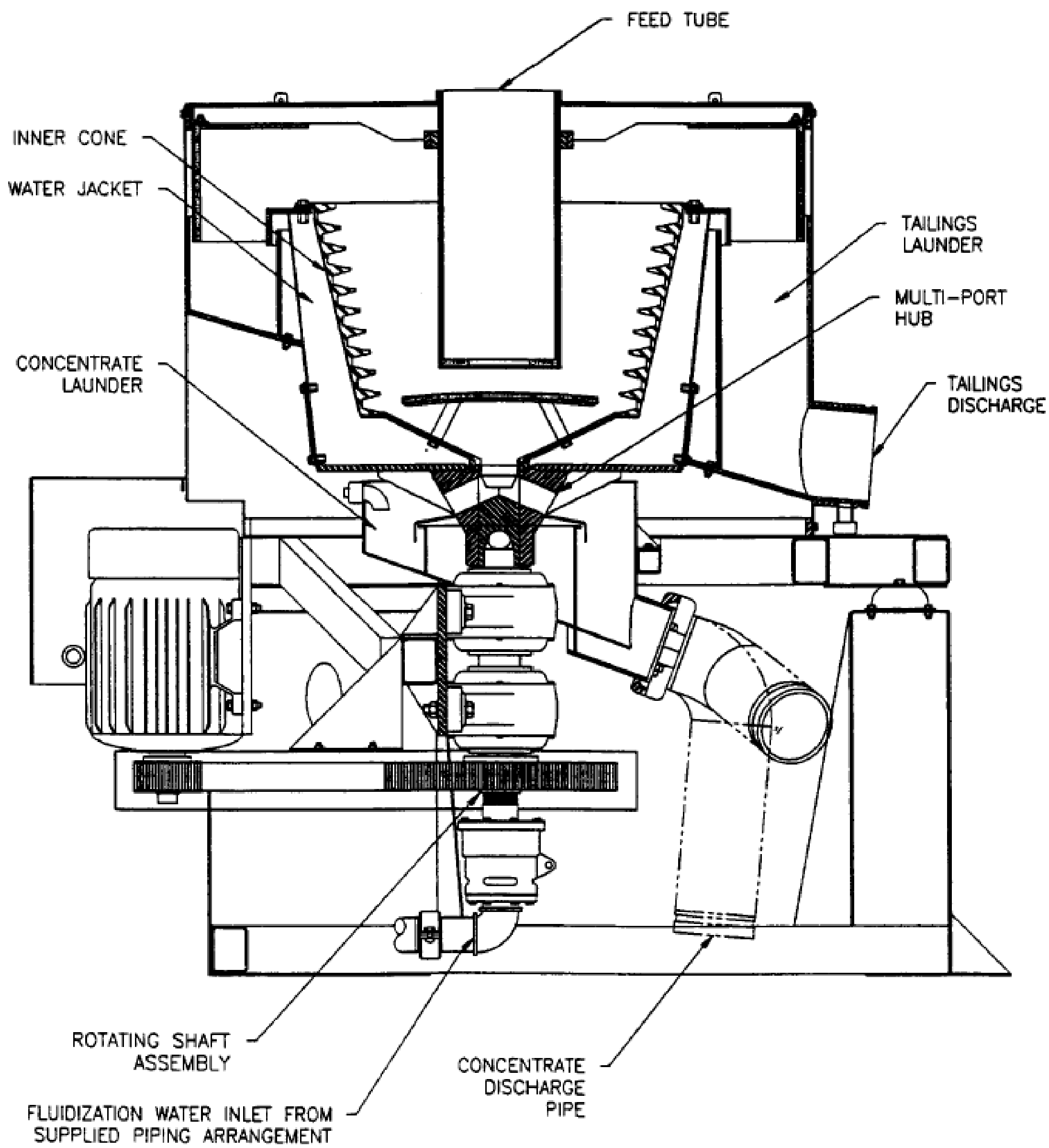

Figure 4: Cross section of KC CD30 Knelson concentrator (Knelson and Jones, 1994)

The concentrating cone of the Knelson concentrator underwent evolution from its inception in the eighties. A wedge shape profile was incorporated to the inner rings of the cone in 1984 to overcome the non-uniform concentration of material in the earlier square designed rings. A rib profile was designed to limit the mass of material at the back wall of the rings. This design is referred to as the generation 4 (G4) cone (Knelson and Jones 1994). The G4 cone produces high mass yields and uses more water than other Knelson cones. It is particularly suited when operating in primary grinding circuits with high sulfide ores, particularly if large amounts of pyrite are present. The generation 5 (G5) cone (Figure 5) was developed for primary grinding circuit applications where less water use is required or less concentrate mass must be produced. In this bowl, only every second concentrating ring is fluidized reducing both concentrate mass and water consumption by nearly 50%. The regular fluidized concentrating rings recover gold particles in all size classes, while the smaller unfluidized concentrating rings recover mainly the fine particles at high-grade.

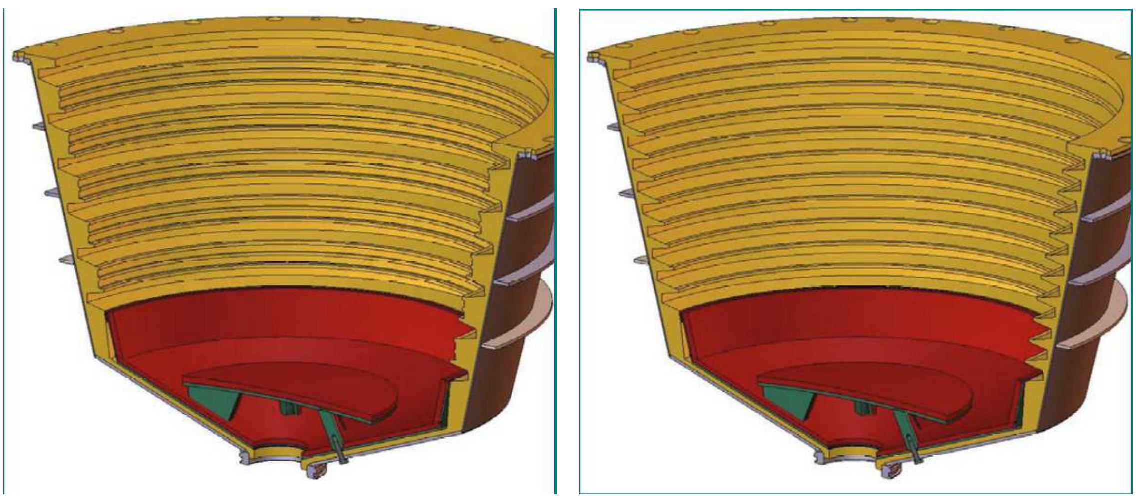

Figure 5: The G5 low mass yield, low flow cone G6 high mass yield, low flow cone (www.Knelsongravitysolutions.com)

Figure 5 also shows the image of the G6 cone. The generation 6 (G6) cone is a fully fluidized cone designed for primary grinding circuits for producing high concentrate masses, for which an Acacia Consep leach reactor (www.consep.com.au) could be used to intensively leach the Knelson concentrate. The G6 cone uses a mix of fluidization flow rings of the standard cone and reduced flow rings to produce maximum concentrate in all size classes. Compared to the G5 cone, the water requirements are slightly more for the G6, but not as high as for the G4 cone. The latest development is the G7 cone, originally developed for the Kemess Mine in BC, Canada for recovery of fine gold in a flotation regrind circuit application (Froehling et al., 2007). The G7 cone is fully fluidized but designed especially for recovering fine gold. Water requirements are low and the G7 cone is normally operated at high G forces. The Kemess Mine test work showed that more than 50% of the gold recovered was smaller than 25 µm.

2.4 Falcon SB concentrator

Falcon SB concentrators are also semi-continuous centrifuge units targeting the same applications as the Knelson CD and XD, but generally operating at a relatively higher G forces, 120 to 180 G. These units were initially developed for recovering fine gold, for example from flash flotation concentrates. They have since been used to recover gold from grinding circuit streams. Falcon SBs are manufactured in different sizes, from laboratory-scale to high capacity models, with automated or manual discharge mechanisms. The manual discharge lab unit, SB40, has a concentrating surface of roughly 40 square inches, and a diameter of 4 inches. The largest unit, the SB5200, is capable of treating up to 400 t/h. The bowl is rotating in a vertical axis, like the Knelson, but its geometry is different, as shown in Figure 6.

Its lower part is smooth and tapered inwards and its upper part consists of a certain number of fluidized riffles (two for the SB40 and three for the SB5200) for concentrate collection. The grooves are evenly perforated for back-injection water to fluidize the concentrate bed and they have the same diameter. Operation cycles are much like those of the Knelson units. For industrial scale units a built-in spray manifold extracts the concentrate.

Besides processing a bleed of cyclone underflow, Falcon SB concentrators are also used to treat cyclone feeds in some plants. However, the advantage of processing cyclone feeds over processing a bleed of cyclone underflow is not significant from a metallurgical point of view.

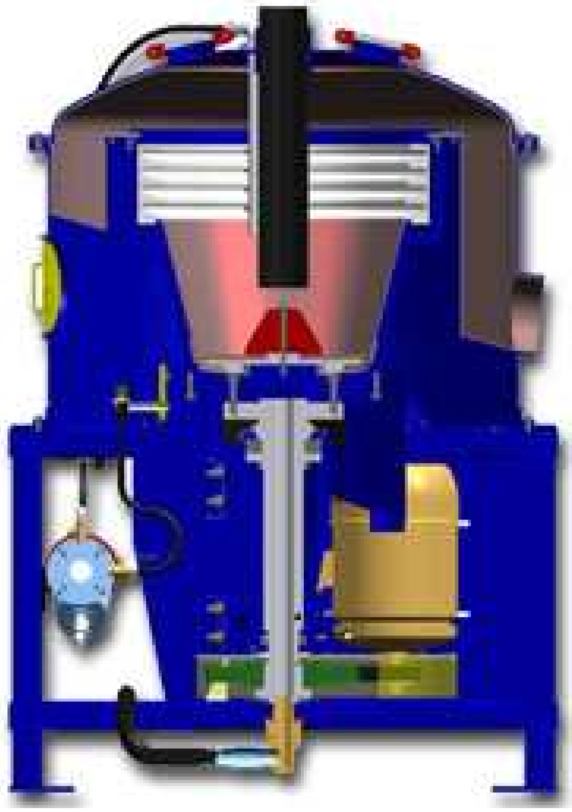

Figure 6: Cross section of a Falcon SB Concentrator (Falcon Concentrator Web site)

A superficial comparison of the Knelson CD/XD and the Falcon SB suggests that:

- The generally higher rotation velocities of the Falcon will make it possible to recover finer gold but may hinder coarser gold recovery;
- The Falcon bowl has a limited fluidized groove surface at the top circular portion and a large conical non-fluidized section at the bottom. These grooves have the same theoretical accelerations, which may not be optimal for a wide range of particle sizes;
- The Falcon's large unfluidized section and lack of vibration dampening system makes it more susceptible to vibration problems. As a result, the Falcon generally requires more dilute feeds than the Knelson;

- The Falcon has an impeller that accelerates the slurry upon feeding. This may assist the slurry in accelerating to the same rotating velocity as the bowl, particularly at high feed rates and low retention times.

Only comparative testing of both units could validate the above points.

2.5 Laboratory Knelson concentrator

The Laboratory Knelson concentrator (LKC) has a 3-inch (7.5 cm) concentrating cone and hence is also referred to as KC MD3 (MD refers to manual discharge - the mechanism of concentrate removal). Significant efforts have been made to understand the operating principles of the LKC. Meza et al. (1994) used a LKC to study the effect of fluidization flow rate and feed pulp dilution on the recovery of fine alluvial gold and reported recoveries over 98% at a water pressure of 14 to 20 kPa from a three-stage test. Luttrell et al. (1995) evaluated the performances of centrifugal gravity separators including Knelson concentrator for fine coal processing and found that these units were capable of recoveries above 80% with good rejection of ash and sulphur. Ancia et al. (1997) compared the performance of Knelson and Falcon concentrators and reported decreased recoveries with decreasing particle size for the KC unit. They also explored the utilization of these units for the concentration of less dense minerals like galena and ilmenite. Harris (1984) presented results of tests of a 12-inch (30 cm) Knelson concentrator in both field and laboratory applications. Results from these tests indicate the versatility and efficiency of Knelson concentrators for recovering fine free gold for both alluvial and hard rock applications.

Forssberg and Nordquist (1987) reported on pilot plant test work using flattened lead shot as a model “heavy”. The operation was atypical of the Knelson units as they were aimed at achieving unusually high concentrate grades (~10%). Recently, Coutler and Subasinghe (2005) developed a model for optimizing the performance of operating Knelson concentrators using a laboratory Knelson concentrator. Extensive research work was conducted at McGill University on a laboratory Knelson concentrator (LKC) both analyzing the fundamental aspects and industrial applications. The work will now be summarized.

2.6 Experimental characterization of a laboratory Knelson concentrator

Research work conducted at McGill University showed that the 3-inch (7.5 cm) LKC unit is a valuable tool to determine the gravity recoverable gold (GRG) content of an ore sample and also for characterizing plant KC performance (Banisi et al., 1991; Laplante and Shu 1992; Laplante et al., 2000). The test produces reliable and reproducible results within ±5% for representative samples from the same origin, typically a mill feed sample, extracted even years apart (Laplante et al., 2000). Thus the GRG test has become an industry standard for assessing the amenability of gold ores for gravity recovery (Huang and Koppalkar 2007). Evaluating an alternative to the GRG test, Subasinghe (2007) considered it as a material characterization test that provides information on the degree of liberation of the ore, the influence of breakage characteristics on liberation and amenability of ore to centrifugal gravity concentration, which are useful for the design of gravity circuits. He further questioned the use of the GRG test for evaluating the performance of existing Knelson concentrators on the ground that the material fed to an industrial KC is of different size and the separating forces acting on the particle are different from those of LKC, leading to different GRG content in different machines. Based on the machine characteristics, Sargent and Subasinghe (2006) and Subasinghe (2008) proposed a performance criterion for determining material recovery in a KC.

A systematic study was conducted to show the effect of operating parameters on the performance of a laboratory Knelson concentrator and its ability to match gold recovery by amalgamation (Laplante et al., 1996). Primary cyclone underflow samples assaying 150 g/t Au, 8% sulphides with a density of 3.2 g/cm^3 from Golden Giant Mine of Hemlo Gold Mines was characterized by processing them with a laboratory Knelson concentrator (Laplante et al., 1996b). The effect of gangue density was simulated by diluting the feed sample at 1:4 either with silica sand or hematite/magnetite to achieve a range of overall densities. The effect of feed rate on gold recovery was studied at three different gangue densities 2.8, 3.2 and 4.0 g/cm^3. Gold recovery decreased with an increasing feed rate above 0.7 kg/min, reaching 66% at a feed rate of 2.1 kg/min for a gangue density of 4.0 g/cm^3. Size-by-size gold recovery showed that highest recoveries were achieved at low feed rate and low feed density. Fines (-37μm) recovery dropped significantly at high feed rate but not at high feed density. The recovery of particles between 75 and 300 μm was most affected by high-density gangue; it was postulated that this is caused by a transition from more spherical particles at fine size to more lamellar particles at coarse size. The effect of this transition would have more impact at higher percent solids, which decreases the porosity of the bed in the KC, making the percolation of the finer flakes (75-300 μm) more difficult, whereas the finer spheres (-37 μm) do not experience these problems. When fluidized water pressure was lowered, sphere recovery was less affected but the recovery of flakes suffered due to poor percolation. The larger flakes, because of their momentum, were less affected. This resulted in a drop in recovery at an intermediate size (i.e., “a trough” in the size by size recovery). A similar recovery dip (trough) was observed when a magnetite-silica feed was processed with a Falcon B6 concentrator (Buonvino, 1993), which ruled out an effect of particle shape (magnetite is not lamellar) and identified particle size as the main factor responsible for the recovery trough. The study on a Hemlo gold sample also provided some important insights for plant Knelson concentrator operation such as:

- Feeding a wide size range reduces KC efficiency, as optimum fluidization cannot be achieved over the full size range;
- Coarse gangue particles decrease efficiency;
- Removal of oversize is warranted when gold is liberated at a fine size;
- Secondary treatment in a smaller KC unit should be performed at low feed rates to minimize losses.

2.7 Use of laboratory Knelson concentrator

The laboratory Knelson concentrator (LKC) is a tool to characterize ores and for evaluating the performance of industrial gravity circuits (Putz et al., 1993; Laplante et al., 1994, Laplante et al., 1996b; Laplante et al., 1997).

2.7.1 Ore characterization studies

Gravity recoverable gold (GRG) can be defined as gold in an ore that can be recovered by gravity at a low yield (less than 1%) (Laplante et al., 1995). The McGill University GRG test (Woodcock and Laplante, 1993; Laplante et al., 2000) is a method used to determine the gravity recovery potential of a gold ore. Use of GRG test to estimate gold content in ores has become an industry standard since it:

4.1 Provides the quantity of GRG, its size distribution and liberation size

4.1 Uses a sample large enough to ensure statistical significance and selectivity

4.1 The GRG is assayed size by size to eliminate any nugget effect

4.1 Avoids the usual pitfalls of other approaches such as non-GRG recovery, loss of natural size distribution, gold traps, nugget effect and high yields

4.1 Produces reliable values and provides information for the design of gravity circuits (Laplante and Shu 1992; Laplante et al., 1994; Laplante and Xiao 2001).

2.7.2 GRG test and the gravity circuit design

The amount of GRG in an ore can be estimated using the GRG test/LKC methodology, which is useful for both green field (feasibility of gravity recovery in a grinding circuit and selection of gravity unit) and retrofit (replacing the existing units for improved performance) applications. The test uses a representative sample as small as 30 kg for high-grade fine gold and as large as 150 kg for low-grade coarse gold. The GRG test consists of three sequential liberation and recovery stages with a LKC, first stage at 100% finer than 850 µm. A second stage conducted at 45-60% passing 75 µm with part of the tailing of stage 1(typically 27 kg) as feed. The third stage performed, typically at final grind of 80% -75 µm using most of stage 2 tailings. Progressive grinding (as opposed to testing at final grind) limits smearing of coarse gold present in the crushed feed sample. The test simulates the progressive liberation and recovery of gold normally achieved in grinding circuits and provides a GRG size distribution. (Laplante, 2002, Laplante and Xiao, 2001). Figure 7 shows the procedure for measuring GRG content with a 3-in (7.5 cm) laboratory Knelson concentrator.

For characterizing the Gravity Recoverable Platinum Group Minerals (GRGPGMs), the GRG protocol developed for gold is adapted with an additional stage of grinding (fourth stage) and processing at a higher rotating velocity since most PGMs tend to report to finer size classes and have a lower specific gravity than native gold (Xiao and Laplante, 2004).

The test also provides information for the design of gravity circuits (Laplante and Shu, 1992; Laplante et al., 1993; Woodcock, 1994, and Laplante et al., 1994). The main advantage of processing a sample with a LKC is that it produces a concentrate of low mass, which can be fully assayed size-by-size to include any “nugget effect” (the nugget effect is a result of the low concentration of valuable minerals coupled with a small number of particles that make up this concentration, thereby making it difficult to obtain a representative sample). This GRG protocol has been applied to some 200 samples with GRG content varying from 3 to 97% (Huang and Koppalkar 2007).

The GRG test is also used to assess the level of gravity recovery in a plant, to design flow sheets and to optimize gravity circuits. The size distribution of the GRG and the specific gravity of the gangue are the two most important variables used for flow sheet selection. The specific gravity of gangue becomes important, typically ores with high sulphide content. For processing ores with high but fine GRG content, screening at 200 to 600 µm is suggested.

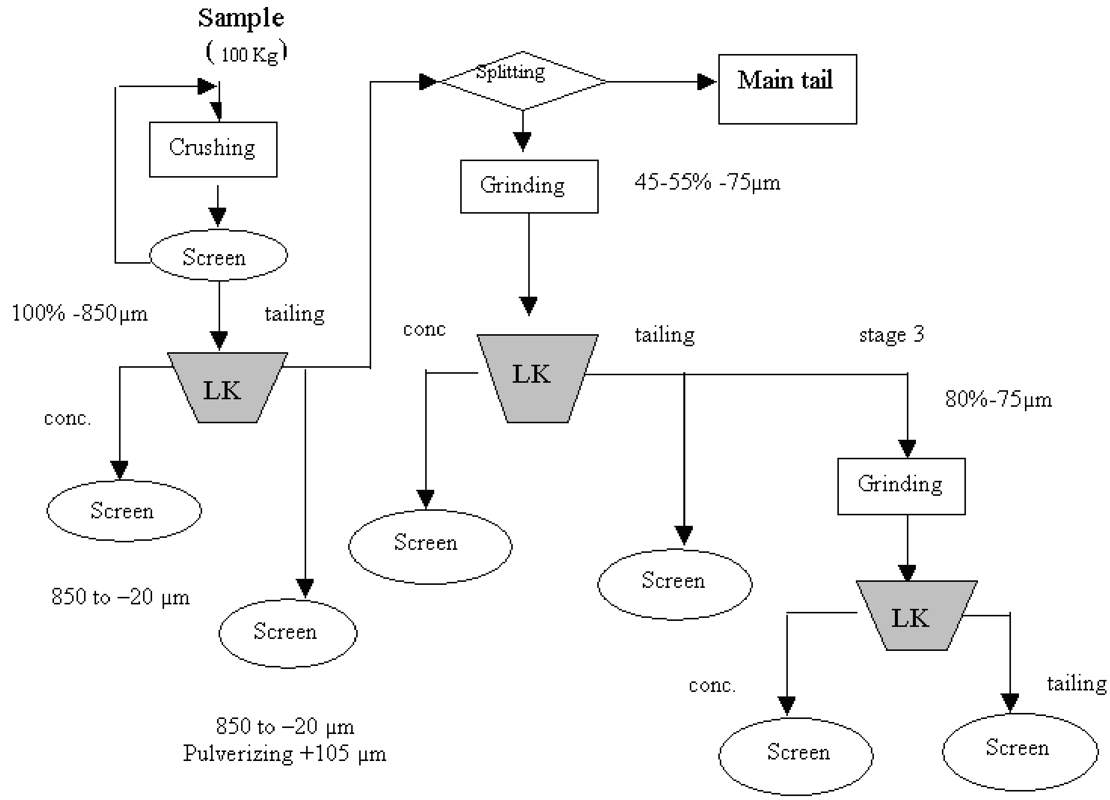

Figure 7: Procedure for measuring GRG content with a LKC (Laplante and Xiao, 2001)

The GRG test not only assesses the amenability of an ore to gravity recovery but also produces particularly appropriate "gravity tailings" that could be used for testing downstream recovery by either flotation or cyanidation (Laplante and Dunne, 2002). One recent work showed that the GRG could effectively be used to better understand gold-copper recovery of low-grade gold-copper deposits (Nesset et al., 2005). A short version of the GRG test called "simplified test" (Laplante and Clarke, 2006) was also developed to meet the typical needs of the industry. In the short version, a sample mass of 20 kg is processed. The sample is processed directly at the last stage of the three-stage test. The simplified test can be used when samples to be tested are in short supply to perform the three-stage test, large number of ore types needs to be tested and for routine testing to track changes in ore type and gravity circuit performance. The simplified test produces similar results for non-abrasive ores but underestimates GRG content for abrasive ores. This is due to the smearing of gold on to the surface of gangue particles, caused by the conversion of GRG and increase in non-GRG content above 20 µm.

2.8 Studies on industrial gravity circuits

The LKC methodology has been used to characterize the GRG content of stream samples of a number of grinding circuits for either retrofit or optimization studies.

Table 2: Summary of the gravity circuit studies based on GRG test

Mine site	Circuit/unit studied	Results/suggestions
Les Mines Camchib; Quebec	30-in PKCs(2); the behaviour of gold analyzed	Gold recovery improved from 20-40%
Aur Louvicourt, Quebec	30-in PKC circuit analysis	Discontinuing of gravity circuit.
Agnico-Eagle Laronde, Quebec	Low GRG recoveries in 30s	Oversize removal
Barrick's Est Malratic, Quebec	30-in PKCs ,GRG recovery 57%	Operate one PKC for coarse and one for fines recovery
Cambior's Chimo Mine, Quebec	30-in PKC circuit studies	Increase feed rate to PKC
Snip Operations, BC	Gravity circuit studies	Replace jigs with PKCs for improved recovery
Golden Giant, Hemlo, Ontario	Gravity circuit studies	Replace jigs with a PKC
Weathered ore, Australia (Flotation)	Circuit studies; fine GRG	Flash flotation and gravity recovery from flash concentrate
Casa Berardi, Quebec	Circuit studies; fine GRG	Fine screening of KC feed at 300 µm

Table 2 lists some of these studies, describes the type of application and summarizes some of the outcomes. Performance of gravity units such as jigs, spirals, Reichert cones, and flash flotation cells in a grinding circuit have also been assessed using the GRG test (Putz et al., 1993; Laplante et al., 1994, Laplante and Dunne, 2002).

2.9 Upgrading gold concentrates using a laboratory Knelson concentrator

Further upgrading of gold concentrates is typically done using shaking tables, either Wilfley or Gemeni. Gold recoveries achieved by tables are operator-sensitive and are often lower (80-90%) as fine and/or flaky gold particles are lost. As the KC is capable of achieving significant recoveries below 37 µm, its concentrate should be upgraded by a unit capable of recovering fine gold into smeltable product.

To address this problem, Huang (1996) investigated the use of the Knelson concentrator either to replace or supplement tabling. High-grade synthetic feeds designed to mimic table feeds were used to study and model the progressive overloading or concentrate bed erosion of the Knelson concentrator (Laplante et al., 1996a). The test work also clearly demonstrated that virtually all the material present in the grooves at the end of the recovery cycle was coarse gangue recovered at the very beginning of the cycle. By comparison, material at the surface of the grooves was high-grade (85 % tungsten). Additional test work with table tailings samples confirmed the ability of the Knelson to recover a high proportion of the gold lost to table tails, but removal of the plus 212 µm fraction was found necessary to achieve this. This can be explained by the relatively high sulphide content of most table tailings. Intensive cyanidation has since proven to be a much more effective means of treating primary gold gravity concentrates. Putz (1994) was able to achieve high concentrate grade 4000 oz/st (14% gold) with an overall recovery of 96% processing the plant Knelson concentrate with the LKC.

Huang (1996) used low specific feed rates in his work, which could be regarded as reasonable to mimic the proposed application (i.e. recovery from Knelson concentrates or table tailings). His findings can only be cautiously applied to the much higher specific feed rates used for primary recovery.

2.10 Concentrate bed erosion in centrifugal concentrators

Concentrate bed erosion in centrifuge concentrators corresponds to deterioration of performance of the unit over the processing time known as concentration cycle time or recovery cycle time. This phenomenon occurs when gold already recovered on the surface of the riffles of the concentrating bowl is removed by the scouring action of high specific gravity particles such as pyrite. Bed erosion is related to cycle time. Recovery cycle time is the optimum processing time beyond which the performance deteriorates. Typical recovery cycle time for alluvial operations range from 4 to 12 hours whereas for hard rock applications it ranges from 30 minutes to 4 hours, depending on the feed gold grade, specific gravity of the gangue and desired concentrate grade. However, cycle times of 5-10 minutes have been used for a regrind application (Froehling et al., 2007). The first systematic attempt to understand the bed erosion mechanism was made using metallic tungsten (density 19.3 g/cm^3, the same as pure gold) to mimic gold content, with magnetite substituting for sulphides and silica sand for silicates (Laplante et al., 1995a). The tungsten was mixed with silica to conduct binary ore experiments at low bed density and with magnetite for experiments at high bed density.

Synthetic feeds of fine and coarse (80% -100 µm and - 600 µm) silica and magnetite to simulate low and high density gangue and fine tungsten (8-75 µm) to mimic gold were used in bed erosion tests on a 3-inch laboratory Knelson concentrator (Laplante et al., 1996a). Bed erosion was investigated at optimum fluidization water flow rate. Overloading is defined as a progressive decrease of KC performance when too much heavy phase is recovered in the bowl (Huang, 1996). It was found that the nature of the gangue dictates how soon in the loading cycle overload takes place and how severe it is. In fact, of the four gangue types tested, only a coarse (F_{80} = 600 µm) and dense feed (specific gravity = 5.0) triggered significant concentrate bed erosion, which took place almost at the beginning of the recovery cycle. Overload for other gangue types ranged from non-existent (fine light-gangue), to slight (fine dense-gangue), to considerable after a certain amount of tungsten (5 to 60 g) was been recovered (coarse light-gangue). The study demonstrated the importance of removing the oversize to maximize recovery, particularly with a high-density gangue. Huang (1996) proposed that the concentrate builds-up until it becomes exposed to the flowing slurry, at which point erosion begins. The model is similar to that proposed for the Falcon concentrator (Laplante and Nickoletopoulos, 1997), the difference being that the rate of capture in the Falcon was assumed to be proportional to the number of capture sites. The erosion rate constant was found to be sensitive to the amount of magnetite in the feed (varied from 0 to 20%). As a result, overloading of the Falcon was more severe than with the Knelson. Sargent and Subasinghe (2006) showed that the segregation of heavy particles in the gangue bed is a first order process. Further on, Subasinghe (2008) showed that the saturation volume of heavy minerals collected as a function of total mass follows a first order process. He also showed that the volume of heavy mineral collected *V* during an operating time *t* is given by:

$$V = V^* (1- exp^{-kt}) \quad (2.15)$$

where V^* and *k* are the saturation volume for the species and its segregation rate constant respectively (estimated by a least square method fit on the experimental data).

Concentrate bed erosion tests were also conducted with a Falcon B concentrator keeping the size distribution of the feed constant while the magnetite content in the feed was varied from 0 to 20% (Laplante and Nickoletopoulos, 1997). A model was developed to describe the observed overloading of the unit as a function of four basic parameters: a capture rate constant, an erosion bed constant, the maximum mass of heavy material in the concentrate bed and the mass of material fed up to the onset of overloading. Due to lack of data, only the last parameter was estimated and was shown to vary between 2 to 8 kg. Visual observation showed that bulk of the tungsten reported to the bottom of the concentrate bed where it is exposed to the flowing slurry; most of the magnetite was recovered above the tungsten ring, evenly spread on top of the full concentrate bed. Recovery was also affected by increased feed rates and high magnetite content. Size-by-size recoveries showed that the highest recoveries were achieved in the finest size class (-25 μm) at 0% magnetite content. At 20% magnetite content, the recovery of the finest size class dropped rapidly with an increase in feed mass. Erosion of the concentrate bed in a Falcon B6 was attributed to a catastrophic and non-selective bed erosion lowering recovery of all size classes. Erosion tests conducted with gold ores showed that the Falcon B6 unit would overload very rapidly when significant quantities of sulphides were present. Lower sulphide contents would yield a progressive overload condition (Laplante et al., 1994). The proposed model assumed that at the beginning of the recovery stage there is a bed-building phase during which all of the heavies are recovered.

More recently, intensive cyanide leaching has been gaining popularity to treat concentrates due to factors such as high gold recovery, security and lower labour costs compared to using shaking tables whose performance can vary widely and are highly dependent on operator experience and skills. It is anticipated that the intensive cyanidation route to process gravity concentrates will be adopted by gold producers (Laplante and Staunton 2005).

2.11 Studies on a variable speed Knelson concentrator

Ling (1998) conducted a comprehensive experimental study on a variable speed LKC using different types of synthetic materials and evaluated the effect of fluidizing water, gangue density, feed size distribution and feed rate on performance. The recovery mechanism of the Knelson concentrator was investigated by studying the percolation and migration behavior of dense particles in a gangue bed in a gravitational field. To obtain and analyze ring-by-ring concentrates, Ling used a set of rubber stoppers to block the rings, to enable the concentrate to be recovered from each ring. He concluded that rotation speed and fluidization flow have significant effects on the performance of the Knelson concentrator. These variables affect both percolation of gold and the fluidization of the flowing slurry and the concentrate bed. He also found that the rotational velocity, corresponding to an acceleration of 60 G is a reasonable compromise for most recovery applications. However for, fine gravity recoverable material, higher accelerations are recommended. Ling found that the recovery of tungsten decreased gradually and linearly with increasing feed rate and decreasing rotation speed. Loss of recovery was attributed to the reduction in retention time in the inner bowl. He found that the tungsten recoveries decreased from lowest ring to top ring, irrespective of rotation speed and feed rate. This phenomenon was more pronounced at the lowest feed rates; at both rotating speeds of 30 and 115 G. Recovery in the top ring was almost negligible at low feed rates. Ling concluded that maximum recovery of dense particles is achieved at an optimum dynamic balance between the centrifugal force and the drag of fluidization flow, which maximizes the amount of dense particles capable of migrating to the concentrate bed.

Ling also investigated the separation of lower density minerals between 4 and 7.5 g/cm^3 from gangue, which are traditionally recovered by non-centrifugal gravity methods. He found that the loss of fine magnetite (-37 µm) was significant, which lowered overall magnetite recovery.

2.12 Modeling of a Knelson concentrator

Attempts to develop mathematical models for the Knelson concentrator encounter several problems such as complex particle/particle interaction and the conical shape of the bowl results in different centrifugal force acting on the particles within each ring. The effect of fluid drag due to fluidization water that is in turn affected by particle shape is another factor (Coulter and Subasinghe 2005).

A mechanistic model was developed by Coulter and Subasinghe (2005) to describe the operation of a KC by considering the main forces acting on the particles within the concentrating bowl. They postulated that the deportment of particles is dependent on the dynamic equilibrium between the fluid drag, centrifugal and Bagnold’s forces, which are function of material properties and key operating parameters such as fluidization flow rate and rotation speed. For a particle to be retained in the rings, the required centrifugal force must be provided by drag and Bagnold forces (a particle moving to the periphery of the bowl encounters particles of the loosely formed bed and experiences a particle/particle interaction force referred to as Bagnold’s force):

$$F_c = F_b + F_d \qquad (2.16)$$

where F_d is drag force, F_b the Bagnold force and F_c the centrifugal force.

Any disturbance to this dynamic equilibrium either retains the particle in the rings or rejects it to tailings. Since both F_c and F_b are related to ω (angular velocity), their combined effect can be represented by a net force F_c^*. The authors postulated that the probability of a particle being retained in the rings must be dependent on the relative net force to drag force, suggesting:

$$X = \frac{F_d}{F_c^*} \qquad (2.17)$$

The magnitude of the drag force depends on the fluidization flow rate and particle size while the magnitude of the net force, F_c^* varies with rotation speed, particle size and density. A high value of X indicates a high drag force due to fluidizing water force that would eject the particle. On the other hand, a low value indicates the net centrifugal force required for a particle to orbit is not supplied by the drag force. This makes the particles travel toward the periphery of the bowl. The parameter X is an indicator of the relative strength of net centripetal force and fluid drag.

Using synthetic materials (combinations of silica and magnetite) and conducting experiments in a 3-inch laboratory Knelson concentrator, the recovery at different sizes and densities was determined as a function of fluidization water flow rate and rotational speed. Coutler and Subasinghe modeled the volumetric material collection (V_i) and the retention parameter for the mixture composition by:

$$V_i = V_{0i} . f_i . \exp\left(- \left[\frac{X_i}{X_i^*} \right]^n \right) \qquad (2.18)$$

where V_{oi} is the maximum volume of material retained under a given set of conditions, f_i is the volume fraction of mineral in the feed, X^* is the critical value of X at the transition between two regions and n is an exponent. The V_{oi} parameter is dependent mainly on particle density and the interactive effect between density and size. Using equation (2.18) the volume recoveries of minerals both in size and density mixtures were determined for a range of operating conditions. To relate the performance of the laboratory unit to an industrial size KC, data were generated on a 30-inch plant KC with volume recovery of gold, sulphides and gangue determined as a function of X. The values of X were about two orders of magnitude higher than those of a 3-inch LKC. Higher fluidization water flow rates to the 30-in KC gave rise to a higher drag force while higher G forces on the mineral particles were generated by increased bowl diameter and rotation speeds. The value of X increased as a function of fluidization water flow rate and recoveries decreased accordingly.

Because of the very low mass (800 to 1000 g) processed during the experiments, the performance reported does not represent realistic KC operation, particularly leading to bias on GRG (Laplante, 2000a). Furthermore, the work of Huang (1996) clearly demonstrated that a concentrate bed growth mechanism, rather than replacement, is responsible for the sustained recovery of the very high-grade portion of the concentrate volume.

2.13 Modelling of gravity recovery circuits

A novel methodology proposed by Laplante et al., (1995a) estimates gold recoveries in the grinding circuits located in the circulating load of secondary grinding mills. A population balance model representing gold liberation, breakage and classification behavior and using data on GRG the gold recovery in grinding circuit is predicted. The link between the GRG content of the ore, F and overall Gravity recovery, D (both column matrices) is given by

$$D = C * R * [I - B * C * (I - R)]^{-1} * F \tag{2.19}$$

Matrices B, C and R represent size reduction, classification and unit recovery of GRG respectively.for recovery from cyclone underflow. This model was used to check the performance of gravity circuits at Casa Berardi, AELRD (Agnico-Eagle Laronde Division) and Resources Meston. The method involves size-by-size estimation of grinding, classification and recovery parameters, which is not trivial. Thus a simplified approach using multi-linear regressions was developed to predict gold recovery (Laplante and Xiao, 2001). They attempted to represent the link between the recovery effort (defined as the product of the circulating load treated by the primary gravity unit, the recovery of this unit and the gold room recovery), the size distribution of GRG and the fineness of grind by multilinear regressions. These regression equations were developed to estimate gold recovery in grinding circuits based on the population balance model (Laplante et al., 1995a). Two regressions, one for coarse GRG and another for fine GRG, were produced. This model was validated using industrial grinding circuit data from different mines.

For the fine GRG size distribution data set:

$$R_{fGRG} = -233.09 + 17.10 * \ln(R_e) + 3.61 * \ln(R_e) * \ln(\tau) + 60.71 * \ln(R_{-25\,\mu m}) - 11.92 * \ln(\tau) - 4.34 * \ln(GRG_{-25\mu m}) - 57.77 * \ln(GRG_{-75\mu m}) + 55.51 * \ln(GRG_{-150\mu m}) \tag{2.20}$$

For the coarse data set:

$$R_{cGRG} = -65.4 + 15.59 * \ln(R_e) + 5.49 * \ln(R_e) * \ln(\tau) + 37.81 * \ln(R_{-25\,\mu m}) - 17.26 * \ln(\tau) - 30.04 * \ln(GRG_{-75\mu m}) + 12.67 * \ln(GRG_{-150\mu m}) \tag{2.21}$$

R_{fGRG} and R_{cGRG} are the GRG recoveries of fine and coarse GRG size distributions, respectively.

$GRG_{-25\mu m}$ is the cumulative GRG content below 25 µm, in %,

$GRG_{-75\ \mu m}$ is the cumulative GRG content below 75 µm, in %, and

$GRG_{-150\mu m}$ is the cumulative GRG content below 150 µm, in %

R_e is the recovery effort and τ is the dimensionless residence time in the ball mill.

$R_{-25\mu m}$ is the proportion of GRG finer than 25 µm reporting to cyclone underflow, which is used to represent the partition curve of GRG.

Factors affecting gravity gold recovery within a grinding circuit have been incorporated in an iterative model, KC Mod*Pro developed by Knelson Concentrators (Grewal and Fullam, 2004). Input variables for the model are: the GRG content of the ore, the fraction of cyclone underflow treated in a gravity recovery unit, the stage recovery of the gravity concentrator, the probability of a GRG particle reporting to the cyclone underflow and the probability of a GRG particle surviving as gravity recoverable in the mill. The values of GRG survival in the mill and cyclone are based on the ranges suggested by Laplante et al. in various publications (e.g. Laplante et al., 1995; AMIRA-P420B). It was shown that the recovery of GRG is highly dependent on the ability to prevent conversion of the gold into non-GRG in the grinding circuit and the ability to maximize the efficiency of the cyclone to direct GRG to the underflow. As these losses of GRG are minimized, the proportion of circulating load that needs to be treated to achieve estimated gravity recoveries is reduced significantly. Furthermore, inclusion of recovery by particle size class made the model more robust. The model is used by Knelson Concentrators to make predictions of plant scale gravity recovery and to assist in the design of gravity circuits. The model is claimed capable of predicting GRG recoveries using various devices such as centrifugal concentrators, shaking tables, jigs and flash flotation within the grinding circuit. Using recovery by particle size class approach minimizes the problem of under or over estimation of recoveries.

Chapter 3 Pilot Knelson concentrator KC CD12 test work at Dome mine

3.1 Introduction

Milling dates back to 1910 at Dome Mine South Porcupine, Ontario, where some form of gravity concentration was used to recover free milling gold (Chong et al., 2004). Dome mine was part of the Porcupine Joint Venture (PJV), between Placer Dome Canada and Kinross Gold, subsequently Goldcorp Inc. acquired Porcupine operations. Kinross Gold owns three mines, Dome, Pamour (reopened in 2005), Hoyle Pond and a central processing plant at Dome mine. PJV processes 12,000 tonnes of ore per day (Canadian Mining Journal 2007). Gold is found as coarse native metal in quartz and ankerite veins. The ore contains 2-3% sulphides in the form of pyrite and pyrrhotite. Several varieties of tellurides are present along with minor quantites of scheelite and sparsely disseminated arsenopyrite (Scales, 1989). Conventional crushing and grinding followed by gravity concentration is used at Dome mill to recover free milling gold. A cyanidation/CIP process recovers the remaining gold in the gravity tailings.

A pilot test facility consisting of a Knelson Concentrator KC CD12 unit, a vibrating screen, a dedicated control panel and a sump-pump was supplied by Knelson Concentrators to the Dome Mine (PJV) for the test work.

3.2 Dome mill circuit description

Dome mill receives ore from three main sources: Dome’s open pit and underground mines and Hoyle Pond mine. Dome open pit and underground mines were combined and converted into a “super pit” around 2004. A flow sheet of Dome mill is presented in Figure 8. Ore is crushed in three stages to produce a 80% passing ½” product. Primary and secondary crushing is achieved in a 400HP, 42”x 65” gyratory and 400HP, 7’ standard cone crusher, respectively. The discharge of the cone crusher is fed to a 20’ x 24’ double deck screen that is in closed circuit with a HP700 cone crusher. The screen undersize reports to two 4,000-tonne fine ore bins whereas the oversize is conveyed to a 75-tonne tertiary surge bin that feeds the HP700 cone crusher.

The run-of-mine ½” material from the crushing plant is fed to a grinding circuit with two parallel lines. Circuit-A consists of a 10.5’ x 14’ rod mill, 13.5’ x 20’ ball mill and two KC CD30 Knelson concentrators while circuit-B only has a 16’ x 28’ ball mill and three KC CD30 Knelson concentrators Both circuits run in closed circuit with 15”(380 mm) cyclones.

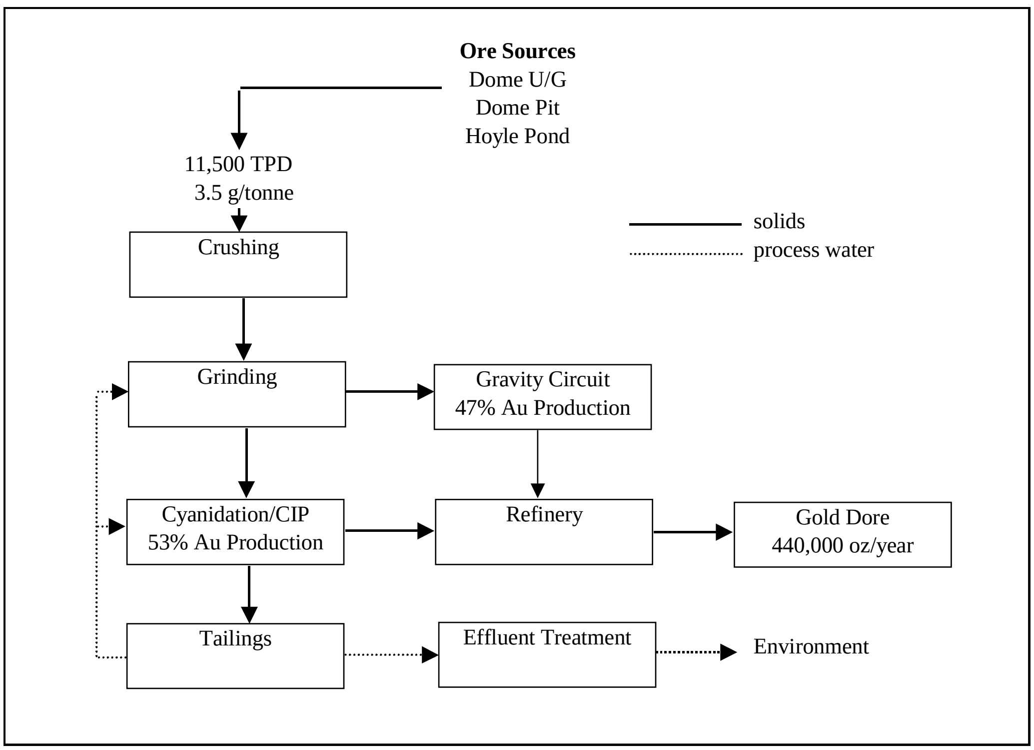

Figure 8: Dome mill flowsheet (Chong et al., 2004)

In 2005, a rod mill was included in grinding-B circuit. The flow sheet of one of the grinding circuits is presented in Figure 10. Gravity gold is recovered by these five Knelson CD30 concentrators processing a bleed of 30% from cyclone underflow.

Knelson concentrates were upgraded using Gemeni tables till 2002 when they were replaced by an Acacia Consep CS6000 reactor to intensively leach the concentrates.

With this modification, gravity recovery increased from 38% to 45-50%. Cyclone overflow reports to a 155’ thickener and the underflow feeds eight leach tanks in series that provide about 15 hours of residence time. Lime is added to the mill discharge pump boxes, thickener feed well and leach tank no.1 to maintain a pH about 11.5 to 12 during cyanide leaching. Cyanide is added to the head of the leach tanks at a concentration of 225 ppm. Oxygen is injected in some of the leach tanks to maintain oxygen level between 15 and 20 ppm.

After leaching, the slurry is pumped to the CIP circuit where dissolved gold is adsorbed by activated carbon in the CIP tanks. Loaded carbon is then removed from tanks and stripped of gold. The elution stripping process transfers the gold from carbon into solution, which is then passed through electrowinning cells where gold deposits at the stainless steel mesh cathodes. The deposit is removed by power washing the stainless steel mesh forming a sludge that is dried and refined in an induction furnace. Gold bullion assaying 80% Au and 15% Ag is cast into bars and shipped to Johnson Matthey Ltd. for refining (Folinsbee et al., 2005).

3.3 Pilot test work

The pilot plant shown in Figure 9 was installed in grinding-B circuit. A bleed valve was installed on the feed of one of the three Knelson CD 30 concentrators treating part of the cyclone underflow. The tailings from the pilot Knelson were discharged to the ball mill discharge sump. This arrangement was later modified by diverting the tailings pipe to a vertical sump-pump in the grinding bay below the mill to eliminate a sanding problem. A schematic depicting the pilot plant in grinding-B circuit is presented in Figure 10.

Figure 9: Pilot Knelson concentrator KC CD12 plant

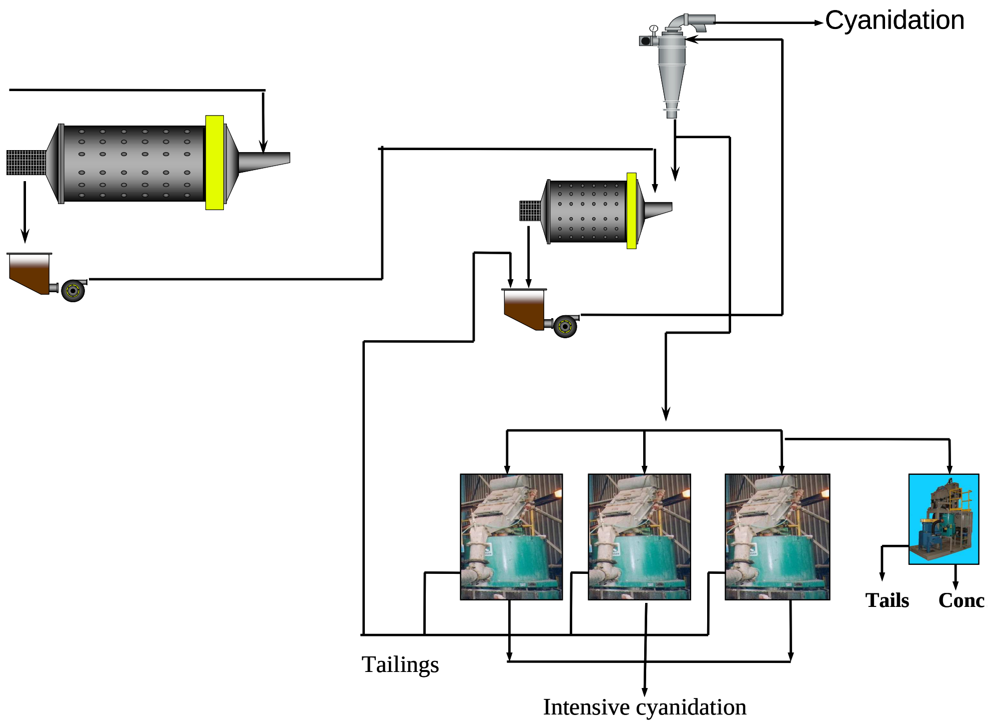

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Figure 10: Schematic of pilot plant in grinding-B circuit

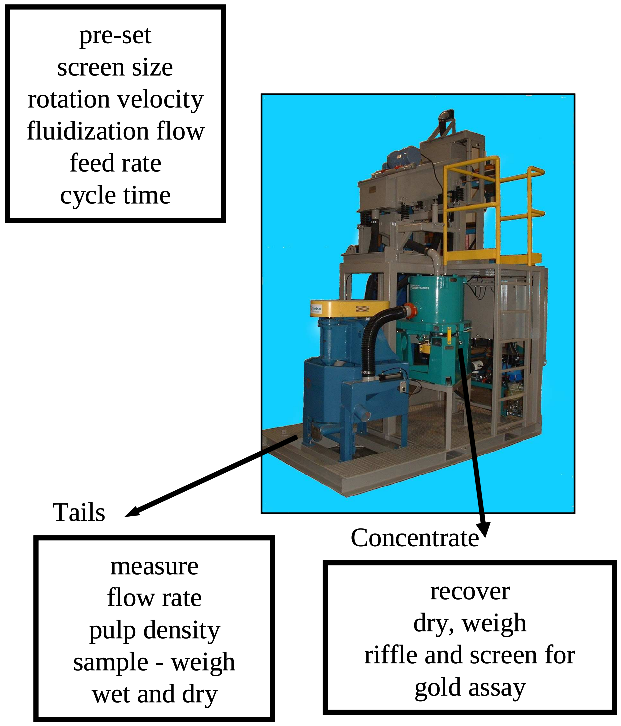

Figure 11: Pilot Knelson test protocol

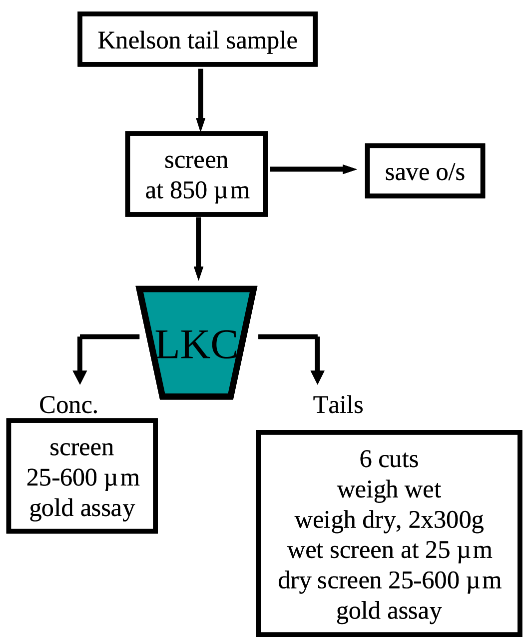

Figure 12: McGill protocol for plant stream sample

3.4 Experimental methodology

The performance of the pilot Knelson KC CD12 was determined using different operating conditions determined by the experimental design discussed in section 3.4.1. The testing protocol used is shown in Figure 11. The McGill protocol for a stream sample, shown in Figure 12, was used to determine the GRG content of the samples generated from the pilot tests. Two types of pilot Knelson tests were conducted: short tests with a 30-minute recovery cycle time, and long tests with recovery cycles of 90 minutes, to cover the range of cycle time of 45 minutes at Dome (Chong et al., 2004). For the short tests, all concentrates were collected at the end of the test, whereas tailing samples were collected during testing. For the long tests, samples were collected with multiple extractions of feed and tailings streams to track the deterioration of recovery with increasing cycle time. In all, 31 pilot tests (26 short and 5 long tests) were conducted in two campaigns.

3.4.1 Experimental design of pilot Knelson KC CD12 tests

Sampling of a pilot Knelson concentrator plant

The experimental design was aimed at providing data for the optimization of the industrial scale Knelson concentrators. The tests were based on a partial 3-level factorial of feed rate and size distribution, fluidization water flow and top feed size. The factorial is partial, meaning that all variables tested will have three independent variables investigated one at a time. It was anticipated that some test conditions may not be achievable but the nearest approach was accepted. If a full experimental design were to be tested, a total of 216 tests (plus repeats) would be tested. This is clearly unrealistic, as each test requires on an average one hour to complete, and generates 30 assays as well as one laboratory GRG determination. Thus a partial experimental design was used with the objective of completing only about 30 tests.

Feed rate: low value (-1) of 2 t/h, average value (0) of 4-6 t/h, high (+1) value of 10-12 t/h.

Feed size: low value (-1) of 1.0 mm, average value (0) of 2.0 mm, high (+1) value of 3.5 mm.

Flow	40 G	60 G	90 G
low	2.3	2.7	4.1
mid	4.1	4.5	5.7
high	5.7	6.4	8.0

Fluidization flow (m^3/h): low, average and high values depend on the rotation velocity, as follows:
Rotation velocity: low value of 40 G, average value of 60 G, high value of 90 G.

For short tests, GRG was determined by sampling the tailings incrementally through out the test and collecting entire concentrate at the end of recovery cycle time. The tailing of the pilot unit were then processed on a LKC to determine the GRG lost in the tailings (proportional to the gold recovered in the LKC). For long tests, concentrate bed erosion was measured. Two methods can be used. The quick method is to sample feed and tailings streams incrementally (0-15 min, 15-30 min, 30-60 min and 60-90 min) and recover the final concentrate at the end of the cycle time. This method assumes that the differences in recovery are such that they can be measured accurately from the difference in feed and tailings assays. The second method is to perform four separate tests with the different recovery cycles. For brevity, the first approach was chosen in this research. If the differences in recovery are so small that they cannot be picked up from samples, the indication is that concentrate bed erosion is relatively minor, which in itself would be valuable information. Tests were randomized in blocks (Table 3) that minimize changes in feed rate and feed size, as these changes require time.

Table 3: Randomization of the tests

Block #	Feed Rate	Feed Size
1	0	0
2	0	-1
3	0	+1
4	-1	+1
5	-1	-1
6	-1	0
7	0	0
8	0	-1
9	0	+1

Part 1: Varying each variable individually

In Tables 4 to 10, operating conditions are given as coded variables and the first column as the "blind" test number; the sixth column indicates the order in which the test was performed. The last column shows the actual test number and type Long (L), Short(S) and campaign (C1/C2).

Table 4: Operating condition codes and test numbers

Test #	Feed rate	Feed size	Fluid flow	Rotation vel.	Test # /Campaign
1	0	0	0	0	11L-C1
2	0	-1	0	0	15L-C1
3	0	+1	0	0	18L-C1
4	0	0	-1	0	2S-C1
5	0	0	0	-1	4S-C1
6	0	0	0	+1	1S-C1

Note that 3 of the 6 tests are long tests of 90 minutes to evaluate the effect of feed rate and top size on concentrate bed erosion. Bench scale studies suggest that both variables affect concentrate bed erosion rates significantly and synergistically.

Part 2: Measuring concentrate bed erosion

Concentrate bed erosion was measured for the extreme conditions: low feed rate and fine top size, and high feed rate and coarse top size, to cover a normal range of conditions. It may lead to a strategy, at Dome, of screening fine and using long recovery cycles on some machines, and of screening coarse to maximize throughput at shorter recovery cycles with other units.

Table 5: Concentrate bed erosion tests

Test #	Feed rate	Feed size	Fluid. flow	Rotation Vel.	Test #
7	-1	-1	0	0	5L-C2
8	+1	+1	0	0	12L-C2

Part 3: What is a truly optimal fluidization flow?

The minimum flow should still fluidize all rings and the maximum is defined as 50% more than the minimum. The following tests were planned:

Table 6: Tests to determine fluidization flow rates

Test #	Feed Rate	Feed Size	Fluid. Flow	Rotating Vel.	Test #
9	0	0	-1	-1	10S-C1
10	0	0	+1	+1	1S-C1

Part 4: Do feed size and rate affect optimal fluidization flow?

Does feeding more (or less) of a fine (or coarse) feed mean that the optimal fluidization flow will change?

Table 7: Effect of feed rate and feed top size

Test #	Feed Rate	Feed Size	Fluid. Flow	Rotation Vel.	Test #
11	0	-1	-1	0	16S-C1
12	0	+1	+1	0	17S-C1

Part 6: Can we maximize fine GRG recovery?

This should be achievable at high flow rate of a fine feed. Would increased rotation velocity help? The following tests were planned to provide an answer.

Table 8: Maximizing fine GRG recovery

Test #	Feed Rate	Feed Size	Fluid. Flow	Rotation Vel.	Test #
13	0	0	0	0	14S-C1
14	+1	-1	0	0	2S-C2
15	+1	-1	0	+1	4S-C2

Part 7: Exploring the very coarse feed size of PJV

Because the PJV feed top size is coarse (-6.0 mm) with average to high feed rate, we need to explore this.

Table 9: Effect of coarse top size

Test #	Feed Rate	Feed Size	Fluid. Flow	Rotating Vel.	Test #
16	0	+1	0	0	19S-C1
17	+1	+1	-1	0	7S-C2
18	+1	+1	+1	0	9S-C2
19	+1	+1	0	-1	10S-C2
20	+1	+1	-1	-1	6S-C2

Part 8: Would a more dilute feed (% solids) help?

Table 10 shows the tests designed to measure the effect of diluting the feed with additional water. For purposes of reproducibility, these tests were performed in pairs, rather than being fully randomized.

Table 10: Effect of dilute feed (% Solids)

Test #	Feed Rate	Feed Size	Fluid. Flow	Rotating Vel.	Test #
21	0	0	-1	-1	10S-C1
22	0	0	0	0	14S-C1
23	1	0	0	0	26S-C1
24	0	0	1	0	3S-C1

Table 11 shows the test design of the pilot tests of the two campaigns. Test numbers in the first column indicate the actual number of the tests (not the serial number). High levels of feed rate (+1) proved impractical during campaign 1 because of the coarse top feed size, 6.0 mm, fed to the Knelson concentrators. Efforts to perform tests at high feed rate resulted in screen overflowing, sanding of the tailings sump-pump and the tailings pipe line. However, during the second campaign, tests were performed at high feed rates because of the finer feed used.

Table 11: Pilot tests design

Test #	Test type	Design levels			
	(S/L)	Feed rate	Scree size	Fluid. flow	Rotating vel.
1	Short	0	0	0	1
2	Short	0	0	-1	0
3	Short	0	0	1	0
4	Short	0	0	0	-1
5	Short	0	0	-1	1
7	Short	0	0	0	0
10	Short	0	0	-1	-1
11	Long	0	0	0	0
14	Short	0	0	0	0
15	Long	0	-1	0	0
16	Short	0	-1	-1	0
17	Short	0	1	1	0
18	Long	0	1	0	0
19	Short	0	1	0	0
26	Short	1	0	0	0
1	Short	1	1	0	0
2	Short	1	-1	0	0
3	Short	1	-1	0	-1
4	Short	1	-1	0	1
5	Long	1	-1	0	0
6	Short	1	1	-1	-1
7	Short	1	1	-1	0
8	Short	1	1	1	1
9	Short	1	1	1	0
10	Short	1	1	0	-1
11	Short	1	1	0	0
12	Long	1	1	0	0
13	Short	1	1	1	-1
14	Short	1	1	0	0
15	Short	1	1	0	0
16	Short	1	1	0	0

The following aspects were analyzed systematically:

- The effect of each variable varied individually;
- The extent of concentrate bed erosion;
- The determination of optimal fluidization flow;
- The effect of feed size and rate;
- The determination of operating parameters to maximize fine GRG recovery;
- Assessment of the effect of very coarse (-6.0 mm) feed size;
- The effect of a more dilute feed (low % solids) on efficiency of the unit.

Sampling strategies for gravity recoverable gold

Gravity concentration circuits have historically been difficult to evaluate for a number of reasons:

- Large samples are required for making the assessment of gold content statistically sound, especially if coarse free gold is present
- In addition, a laboratory concentration step is often needed to produce an appropriate sample mass for fire assaying
- Duplicate samples are routinely assayed to reduced variability caused by nugget effect

When sampling any process stream care must be taken to obtain a representative sample. For the evaluation of streams containing free gold particles, sampling precision (repeatability) and accuracy (lack of bias) are especially difficult to achieve due to the low concentration of gold particles (nugget effect). Gy (1979) has developed a semi-empirical relationship to estimate the fundamental sampling error (relative variance) or the minimum mass required for a certain sampling accuracy. When the element of the interest is in low concentration and the sample mass is much smaller than the sampled mass, Gy's equation can be written as:

$$\sigma^2 = CLFG\frac{D^3}{M_s} \tag{3.1}$$

Where

C: composition factor, the mass of ore per volume of species sampled (g/cm^3)

L: liberation factor; can be approximated by L= $(D_i/D)^{0.5}$ where D; is the maximum grain size of the species investigated

F: particle shape factor; usually adjusted to 0.5, (1 for spherical shapes and less than 0.2 for flakes)

G: size distribution factor; (1 for monosized material and 0.25 for unsized products)

D: maximum particle size; D_{95} (cm)

M_s: sample mass (g)

σ^2 : Fundamental sampling error

Gy's equation, when applied for gold ores has met with limited success due to the inadequacy of its sampling variance and minimum sample mass determination formulae. Application of these formulae often leads to unrealistically large minimum sample masses (Bongarcon, 1991). This is largely due to the assumption (Gy's) that minimum mass should be estimated based on librated mineral species, corrected with a liberation factor L. This factor is low in equation (3.1) hence high estimation of either σ^2 or M_s. For studying gravity gold circuits where gold is librated this problem is not so critical. Gy's equation overestimates required sample mass, if particle shape factor F, is over estimated. Banisi (1991) has weighed a large number of gold flakes in coarser size classes where sampling problems are severe. This makes it possible to reduce Gy's formula as the relative sampling variance for a given size class is equal to the inverse of the number the gold flakes in that size class in the sample. The overall sampling variance becomes a weighted average of the variance of each size class (Laplante and Shu, 1992).

The large masses required to estimate gold grade accurately in the coarsest size classes are illustrated by Banisi (1991). For the 840-1200 µm class, gold flakes weigh an average 5 mg. For a grade of 10 g/t, the mass required to estimate grade with a relative standard deviation of 10% (± 1 g/t) is equal to 33 kg. If a stream contains 5% weight in the 840-1200 µm fraction, approximately 600 kg unsized material must be extracted. In the 300-420 µm gold flakes average 0.5 mg (Banisi, 1991); to achieve the same 10% relative standard deviation a mass of 5 kg must be sampled. Below 210 µm, pure sampling errors become negligible and errors of screening, assaying, and stream fluctuations in grade become predominant (Laplante, Putz and Huang, 1993).

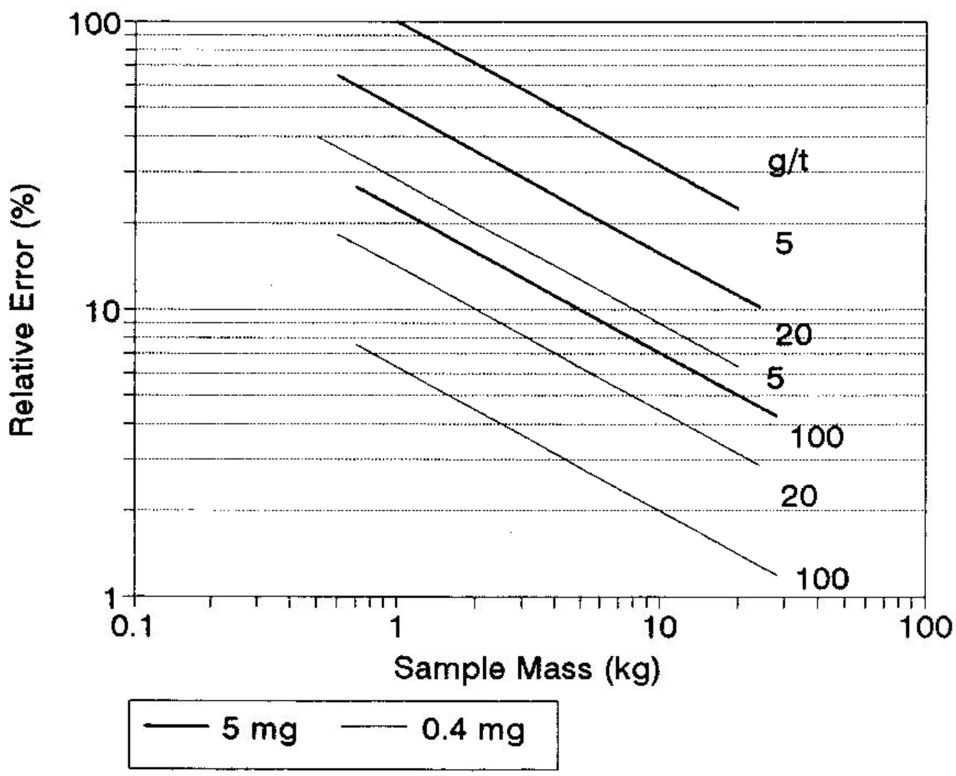

Figure 13: Relative error (standard deviation) on gold content as a function of the sample mass and grade, and flake weight (Laplante, Putz and Huang, 1993)

Figure 13 offers useful guidelines for sample mass selection and realistic sample accuracy expectations. Generally, if the gold distribution is below 840 µm (0.5 mg gold particles) and the grade is > 3 g/t, a sample mass of 5-20 kg would be representative. This sample size would also yield good size by-size information (relative error < 10%) when grades are at 20 g/t or higher. Clearly, in most cases it is difficult to generate acceptable information above 840 µm (5 mg gold particles) and alternatives, such as the use of tracers (Walsh and Rao, 1986, Clarkson, 2003), should be sought for sampling.

The next important step is assaying all of the free gold in large samples. The representative sample acquired in the plant must then be prepared to produce a representative sub-sample of a suitable size for assay. It has been shown that small sample size or large gold particle size invalidate an assay of small samples (Putz, 1993). Pre-concentration of samples would help to eliminate this problem by assaying the entire smaller mass. KC recovers gold that is GRG, as its yield or mass recovery is typically <1%, and therefore the probability of recovering significant locked gold is low. To verify this, Laplante, Putz and Huang (1993) showed that when feeds known to contain little gravity recoverable gold are fed to the KC, gold recovery is particularly low, even if the gold content is high.

Processing of the pilot plant products to determine GRG recovery

The second step was processing of the samples extracted to determine the GRG content size by size. The Pilot test concentrates were dried and split to retain a quarter of the mass for determining size by size gold content whereas the tailings were processed as per the sampling procedure of extraction of large samples, 5-20 kg and their processing with a LKC, to characterize size by size performance. The procedure yielded reliable estimates of overall gold assays. The rationale for this approach is discussed in Laplante and Shu (1992) Laplante (1993). The concentrate and tailing fractions were screened on two different set of screens to minimize contamination. Fifty GRG determinations were carried out on a LKC requiring a total of around 1400 gold assays.

Material balance and analysis of the metallurgical data

The pilot KC concentrate had coarser size fractions (1700 to 850 µm) having significant gold content with no corresponding mass in the tailing sample (the general practice is to screen both the concentrate and tailings at the same screen top size). The coarser size fractions are assayed and then combined mathematically to the concentrate size class (600 µm) corresponding to the coarsest size class assayed for the KC tailings to calculate the metallurgical balance (otherwise the calculated recovery of the coarsest size class is 100%) Laplante (1993). The sample on a LKC is processed in such a way that GRG recovery is maximized (i.e., 95 $\%^{+}$); the rationale for this approach is discussed in Laplante, Putz and Huang, (1993). It was also shown that below a F_{80} of 400 µm and a gangue minerals density of 3.2 g/cm^3 the recovery obtained by KC are equal to 95% of amalgamation recovery (Spillers, 1982, Banisi, 1991). Since in most gravity circuits recovery typically takes place below 850 µm or the information is sought below 850 µm, the size limitation is not critical and if it is, as an alternative approach is the use of radioactive tracers (Laplante, Putz and Huang, 1993). Thus, all pilot tailing samples were screened on 850 µm prior to processing on a LKC (Figure 12). Detailed metallurgical balance was carried out for all the tests using the equation (3.2). The data will be used to evaluate the performance of the pilot Knelson concentrator as a step towards understanding the full scale Knelson performance.

3.5 Pilot sampling and sample processing

The pilot test work was carried out over two campaigns. However, the pilot plant could not handle the very coarse feed size (-6.0 mm) during the first campaign. After some modifications to the screen discharge chute, addition of water jets in the tailings pipe line and boosting of the power of the tailings motor, fifteen tests (12 short and 3 long tests), were conducted. High feed rate tests (high level) could not be conducted due to frequent sanding of the tailings pump. At the beginning of 2005, a rod mill was added to grinding circuit-B circuit (Figure 10), producing a finer feed size. The second campaign ran smoothly and all remaining tests were completed. It was anticipated that the results of campaigns 1 and 2 would yield different data sets because of the changed feed conditions.

At the beginning of each test, the required screen panel was installed and other operating parameters like the rotation speed, fluidization water flow rate and recovery cycle time were set at the beginning of the recovery cycle. Feed to the pilot unit was then introduced by opening the 4-inch bleed valve installed on the feed pipe to one of the Knelson concentrators. Concentrates, discharged automatically at the end of the test were fully recovered. KC tailings were sampled manually at timed intervals throughout the recovery cycle using a specially designed pulp sample cutter. A Marcy scale was used to check the pulp density of the tailings stream during the test. Flow rates were measured using a calibrated container and a stopwatch. Samples collected during the pilot testing were weighed wet and filtered at the mill site. The wet cakes of feed, tailings and concentrates were then shipped to McGill University for further processing. The samples received from pilot testing were oven dried. Tramp iron was separated with hand magnets from the concentrate samples. The concentrate samples were then cut twice on a Jones riffle. Three-quarters of each concentrates were directly returned to the Dome mine. The last quarter was dry screened down to 25 µm and each size fraction returned to the Dome/Musselwhite assay laboratory for fire assay. Grinding of the samples prior to analysis is not necessary as the entire sample mass was used for determining gold content.

The tailing samples were dried, weighed and screened at 850 µm and the minus 850 µm, varying between 11 and 27 kg in mass were processed with a 3-in laboratory Knelson concentrator to asses the GRG present in the pilot Knelson tailings. The LKC tailings were sampled during processing and 600 g (six samples of about 100 g each) were collected. These tailing samples were then dried, combined, and split into two 300 g samples for screen analysis. Each sample was first screened wet at 25 μm and dry screened from 25 to 600 μm. The -25 μm sample (pan fraction) was thus obtained by combining the wet and dry portions .First six coarse fractions from 600 μm to 106 μm were pulverized since their mass was greater than one assay ton (29 g) prior to assaying and remaining fractions from 75 μm down to -25 μm sent for assaying without pulverizing. LKC concentrate and tailing size fractions were shipped to PJV for assaying. The concentrate fractions both from pilot tests and laboratory Knelson tests were "assayed to extinction" using total sample mass to minimize fundamental sampling error (known as the nugget effect), whereas the tailing fractions were assayed using a maximum mass of an assay-tonne (29 g) sample.

Knelson performance was calculated size-by-size based on the total gold in the concentrate (assumed to be 100% GRG) and the GRG in tailings (assumed to be proportion of gold recovered by LKC). Feed grades were back calculated to minimize error associated with sampling feed to the Knelson concentrator (recirculating stream with fluctuating gold grade) in all metallurgical balances presented in appendix 2.Thus the recovery calculations were made using raw data, concentrate and tailings assays as shown in equation (3.2).

GRG recovery R_i for size fraction i is:

$$R_i = \frac{M_c \times m_i^c \times G_i^c}{M_c \times m_i^c \times G_i^c + 1000 \times \frac{30}{60} \times \frac{\% - 850 \mu m^t}{100\%} \times Q_t \times m_i^t \times G_i^t \times \frac{GRG_i^t}{100\%}} \times 100\% \qquad (3.2)$$

where M_c: mass of dry concentrate (kg)

m_i^c: % mass of concentrate in size fraction i

G_i^c: gold grade of concentrate size fraction i (g/t)

%-850µm^t: % of the Knelson CD12 tailings finer than 850 µm

Q_t: dry flow rate of Knelson CD 12 tailings (t/h)

m_i^t: % mass of tailings in size fraction i (based on -850 µm)

G_i^t: gold grade of tailings size fraction i (g/t)

GRG_i^t: % of gold that is GRG in size fraction i of CD 12 tailings

The above equation is based on a recovery cycle of 30 minutes (hence the 30/60 term).

The error associated with the size by size recovery calculations using the recovery formula is about 12%. This is on the higher side mainly because of the errors associated with: i) ore grade variations, ii) sampling and sample processing errors and iii) errors associated with assaying at different mine sites. The samples of first campaign were entirely assayed at the Dome mine assay laboratory and the samples of the second campaign were partly assayed at the Musselwhite mine and IPL assay laboratory arranged by Knelson Concentrators. Recovery response from any two GRG tests may have identical overall GRG or bulk GRG value but may have different size distributions. This difference in recovery by size impacts the behavior of the GRG within the grinding-gravity circuit and ultimately on gold gravity recovery. Moreover, when fine particle recovery (< 850 µm) is targeted, gold recovery is invariably analyzed on a size by size basis. Thus the results of the GRG tests are reported and analyzed on a gold particle size by size basis in this work.

Chapter 4 Results and discussion

4.1 Metallurgical results of campaign1

Detailed metallurgical balances for the fifteen tests were calculated using the recovery by size fraction equation (3.2) presented in Chapter 3. First a GRG metallurgical balance for the pilot test tail sample processed on a LKC was carried out and then using this information, the metallurgical balance of the pilot Knelson test was calculated. The operating conditions for the twelve short tests (Tests 1 to 26) of 30 minutes recovery cycle and three long tests (Test 11 to 18) of 90 minute cycle time are presented in Appendix 2 (Table 22). The overall results are presented in Table 12. Test numbers are actual numbers (not the serial number) from the experimental design and they are performed randomly to minimize bias.

Table 12: Overall metallurgical results of campaign1

Test #	Screen Size (mm)	Fluidization flowrate (m^3/hr)	G-force	Feed rate (t/hr)	Concentrate % GRG Rec.	Concentrate Grade Au, g/t	Tails GRG g/t	Tails non-GRG g/t	Feed gold g/t
1	2.0	5.7	90	8.8	76.06	5653	3.22	2.45	13.45
2	2.0	2.3	60	9.7	68.39	10275	3.77	3.34	11.91
3	2.0	3.6	60	9.6	76.09	11941	3.14	2.4	13.13
4	2.0	4.1	45	11.3	67.40	11538	3.87	2.14	11.85
5	2.0	4.1	90	10.8	62.63	7768	3.94	3.78	10.53
7	2.0	4.5	60	13.6	48.99	5379	3.24	2.52	6.35
10	2.0	2.7	45	9.3	62.62	4694	2.39	2.27	6.40
14	2.0	2.5	60	14.1	61.47	3044	1.89	2.07	4.91
16	1.0	2.7	60	6.6	81.58	3983	1.07	2.35	5.78
17	3.5	6.4	60	7.8	55.77	1334	2.35	2.89	5.31
19	3.5	4.5	60	13.3	40.03	1463	2.84	2.42	4.73
26	2.0	4.5	60	13.1	51.47	8140	3.92	3.02	8.07
11	2.0	4.5	60	7.75	69.75	11318	1.66	2.68	5.44
15	1.0	5.4	60	7.59	76.79	12891	1.45	1.94	6.23
18	3.5	4.5	60	8.17	54.45	3080	2.21	1.71	4.84

Detailed metallurgical balances of the LKC and pilot Knelson tests are presented in Appendix 2 (Table 23-Table 67).

It can be seen that GRG recoveries ranged from a low 40% to a high of 81% mainly because of the fluctuating feed rates from 6.6 to 14.1 t/h. Test 19 performed at coarse top size coupled with high feed rate produced lowest recovery, 40% whereas Test 16 performed at fine top size coupled with low fluidization water flow rate produced highest recovery, 81.6%.

4.1.1 Effect of feed rate and top size

Overall GRG recoveries for the 15 tests have been plotted in Figure 14 as a function of feed rate for the three feed top sizes. It can be seen that much of the variations in GRG recovery are due to feed rate with top particle size also being a significant contributor.

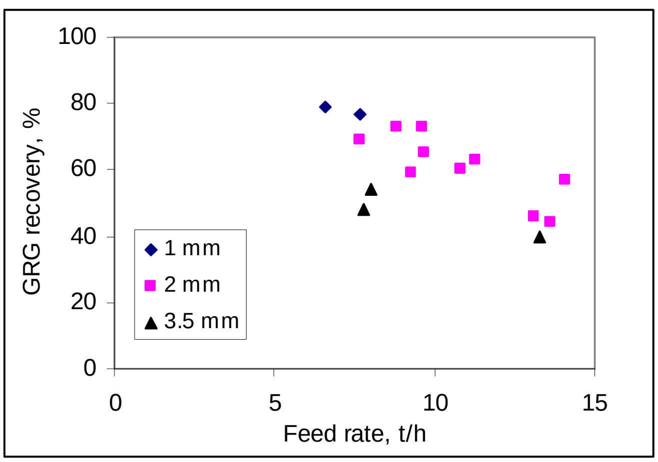

Figure 14: GRG Recoveries as a function of feed rate for the three top sizes

Coarse feed size produced lowest recoveries among the tests indicating clearly that coarse top size is deleterious for improving recovery. Finer top size (1.0 mm) produced highest recovery among the tests, however the effect could not be verified as only two tests were conducted at low feed rate. Laboratory Knelson tests on a high grade cyclone underflow sample indicate that high feed rate and top size synergistically affect recovery

(Laplante et al., 1996). The effect of feed rate and top size on GRG recovery can be fitted to the equation:

$$R_{GRG} = 110.5 - 2.83 \times Q - 9.89 \times X \quad (4.1)$$

where Q is the dry feed rate in t/h and X is the top feed size in millimeters. The regression has lack of fit of 5.8% and a significance of 99.7%. The two coefficients for Q and X are significant at the 95% level. Given the scatter of data, the correlation coefficient is low, 0.81.

4.1.2 Effect of fluidization flow rate

Figure 15 shows size by size GRG recovery for two tests, one at low fluidization flow rate and another at high flow rate to understand the effect of fluidization flow rate on size by size recovery. Test 2, conducted at low fluidization flow rate (2.3 m^3/h) produced high recoveries in all sizes with an overall recovery of 68% whereas Test 19 performed at a high fluidization flow rate (4.5 m^3/h) produced low size by size recoveries and an overall recovery of 40%.

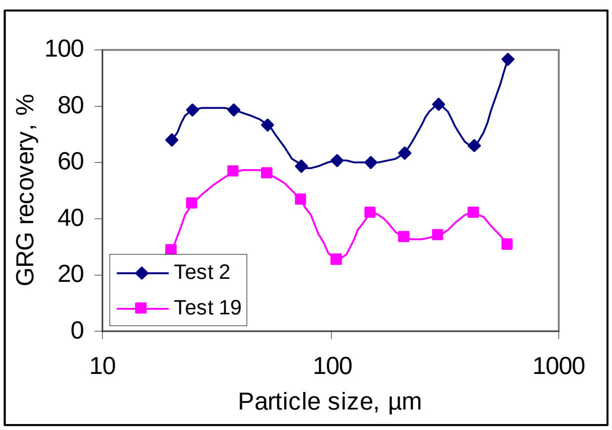

Figure 15: GRG recovery as a function of fluidization flow rate

The low recoveries for Test 19 are attributed to the combined effect of coarse top size, 3.5 mm and high fluidization flow rate, 4.5 m^3/h, which act synergistically to erode the concentrate collected in the riffles.

In Figure 16, the effect of fluidization water flow as a function feed top size is shown. Test 16 was performed with the combination of fine top size (1.0 mm) and low fluidization flow rate (2.7 m^3/h), whereas Test 17 at a coarse top size of 3.5mm and high fluidization flow rate (6.4 m^3/h).

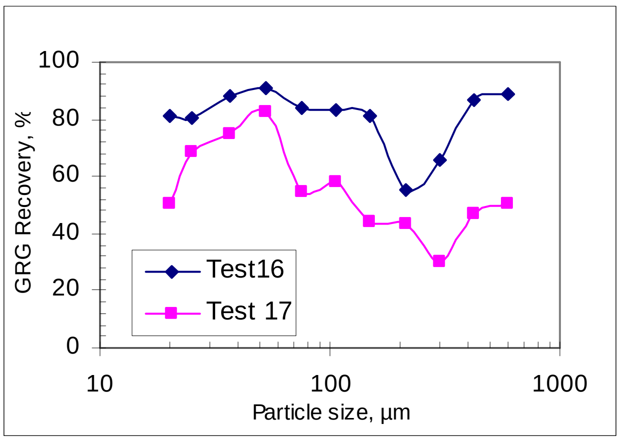

Figure 16: Effect of fluidization flow rate as function of top size

It can be seen that the combination of fine top size and low fluidization flow rate produced relatively high recoveries in all size classes. It can also be seen that the recovery of fine size classes (75 to -25 µm) is clearly better for fine top size. Thus feed rate and top feed size affect synergistically the optimum fluidization flow rate. The dip at 300 µm is (shown in section 4.3) due to the resistance to the flow of 300 µm gold particles offered by the maximum feed mass present at that size.

GRG recoveries for all fifteen tests, averaged separately for low fluidization and high fluidization flow rates are presented in Figure 17. The recovery trend is consistent for both high and low fluidization flow rates, however the averaged test results for low fluidization flow rates produced higher size by size GRG recoveries. Typically for an operating Knelson, low recoveries at the intermediate sizes have been reported due to the suboptimal fluidization water flow rates (Vincent, 1997). However, the low size by size recovery trend is consistent for both high and low fluidization water flow rates.

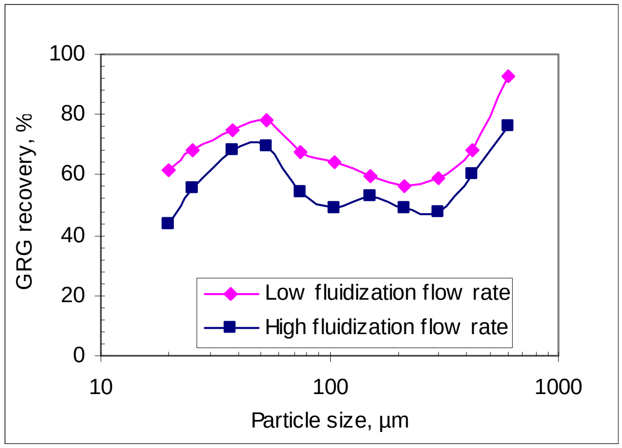

Figure 17: Size by size recoveries as a function of fluidization flow rate

4.1.3 Effect of dilute feed

Four tests, Test 2, 4, 10 and 26 were performed to measure the effect of feed solid concentration by diluting the feed. The measured feed % solids were 41%, 44%, 39% and 35% respectively. Test 10 and 26 were conducted diluting the feed. Figure 18 presents the size by size recoveries of these tests.

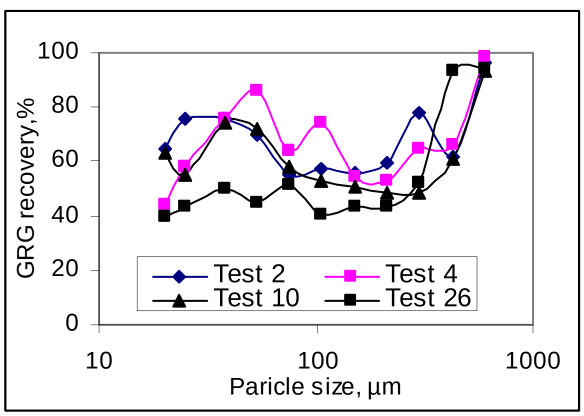

Figure 18: Effect of dilution of feed (% solids) on size by size GRG recoveries

It seems that diluting the feed did not produce any discernible effect on recovery. However, overall recoveries ranged from 51% to 68%. Test 2 performed at 41% solids without dilution produced high overall recovery (not for all size classes).

4.2 Concentrate bed erosion tests-campaign 1

Concentrates from the operating Knelson concentrators at Dome are flushed and collected at about every 45 minutes (Chong et al., 2004). Three tests, Test 11, 15 and 18 represent the long recovery cycle tests of 90 minutes to evaluate the effect of feed rate and top size on concentrate bed erosion. Studies conducted by Huang (1996) on a LKC suggest that the combined effect of these two variables produce significant erosion of the concentrate accumulated in the Knelson concentrating cone. Feed rate to the pilot unit could not be varied due to the coarse feed size, -6.0 mm during campaign-1, however, feed top sizes were varied from 1.0 mm to 3.5 mm. For these tests, samples of the pilot feed and tailing streams were collected incrementally throughout the cycle time coupled with recovering the entire concentrate at the end of cycle time. These samples were processed separately on LKC applying the McGill protocol for stream samples (Figure 12). The results of the laboratory Knelson tests and pilot tests are presented in Appendix 2 (Table 47-Table 67).

Tables 13, 14 and 15 present the results of the concentrate bed erosion Tests 11, 15 and 18 respectively. The GRG in g/t for a stream is calculated from the head gold grade and the corresponding GRG recovery determined on LKC. Using the calculated GRG values of the feed and tail streams, pilot Knelson GRG recovery for a particular increment is calculated as,

$$GRG\,\mathrm{Re}c = 100 * \left(1 - \frac{GRG_{tails}}{GRG_{feed}}\right) \tag{4.2}$$

Table 13: Metallurgical balance of pilot Knelson concentrator for Test 11

Pilot KC	(0-15 min)			(15-30 min)			(30-60 min)			(60-90min)			Overall		
	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG
Feed, g/t	16.8	14.7	2.1	16.8	14.7	2.1	9.7	7.5	2.2	9.7	7.5	2.2	13.2	10.3	3.0
Tailing, g/t	4.4	1.7	2.6	4.1	1.2	2.9	4.4	1.9	2.5	4.4	1.9	2.5	4.3	1.7	2.7
Recovery,%	74.1	88.3	-	75.7	92.0	-	54.9	75.2	-	54.9	75.2	-	67.4	83.9	-

Table 14: Metallurgical balance of pilot Knelson concentrator for Test 15

Pilot KC	(0-15 min)			(15-30 min)			(30-60 min)			(60-90min)			Overall		
	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG
Feed, g/t	8.7	7.1	1.6	8.7	7.1	1.6	7.4	5.5	1.9	7.4	5.5	1.9	8.1	6.0	2.1
Tailing, g/t	3.8	2.0	1.8	2.7	0.8	1.8	3.1	1.5	1.6	4.0	1.5	2.6	3.4	1.5	2.0
Recovery,%	56.8	71.9	-	69.3	88.1	-	58.6	73.0	-	45.6	73.3	-	57.3	75.4	-

Table 15: Metallurgical balance of pilot Knelson concentrator for Test 18

Pilot KC	(0-15 min)			(15-30 min)			(30-60 min)			(60-90min)			Overall		
	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG
Feed, g/t	8.0	5.6	2.4	8.0	5.6	2.4	7.1	5.3	1.8	7.1	5.3	1.8	7.6	5.7	1.9
Tailing, g/t	3.3	1.6	1.8	4.4	2.6	1.8	4.5	2.9	1.6	3.4	1.8	1.7	3.9	2.2	1.7
Recovery,%	58.4	72.0	-	45.4	54.0	-	36.6	44.5	-	52.0	66.8	-	48.2	60.8	-

Test 11 was performed at an intermediate top size (2.0 mm) and feed rate (7.7 t/h) and test 15 at a top size of 1.0 mm and feed rate (7.6 t/h). Test 18 was performed at a coarse top size of 3.5 mm and a feed rate of 8.2 t/h. However, due to the coarse top size of the operating Knelson concentrator feed, high feed rates were not feasible. Hence the concentrate bed erosion was insignificant and little erosion was observed in the second and third periods for the test 18. The results indicate that concentrate bed erosion is relatively minor for the operating Knelson concentrators.

4.3 Overall GRG recovery for the tests of campaign1

The GRG recoveries for the 15 tests have been plotted in Figure 19. Scatter is significant but trends are evident, in the sense that GRG recovery does not decrease with decreasing gold particle size as typically seen in many industrial Knelson performances.

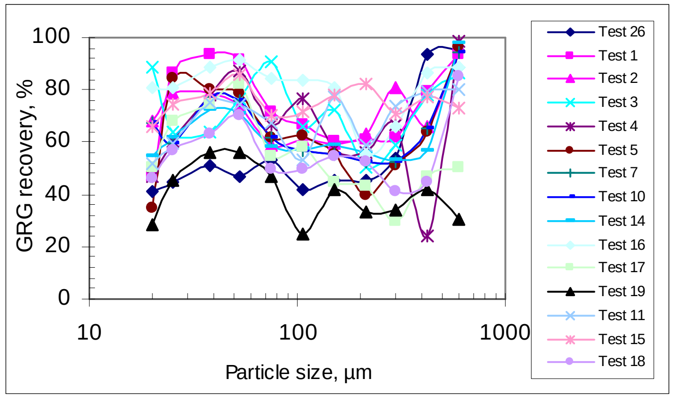

Figure 19: Size by size GRG recoveries for the pilot tests of campaign 1

Secondly, there appears to be a high recovery zone at the coarser end and a second high recovery zone at the finer size end. The size by size GRG recoveries of 15 tests have been averaged and plotted in Figure 20 along with the average feed size distribution for the fifteen tests. The averaged GRG recovery curve confirms the observation made from Figure 19. It can be seen that the shape of the recovery curve that emerged from the averaged data is unusual, in the sense that the typical trend of "decreasing GRG recovery with decreasing gold particle size" is not observed. It can be seen that there is a low recovery zone corresponding to the mode of the size distribution, which is at a size of 212 µm. An averaged particle feed mass, 21% present in the 212-300 µm size class offers resistance to the percolation or flow of the gold particles in that size.

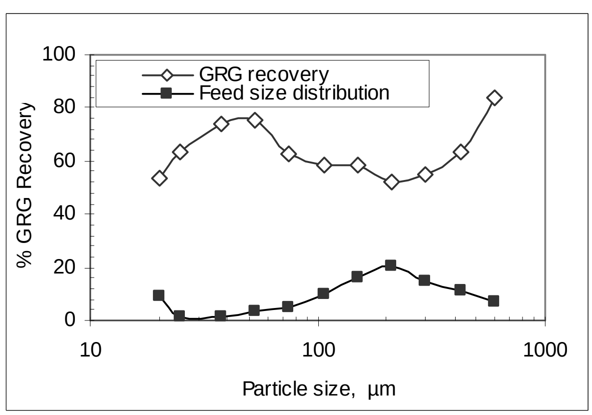

Figure 20: Size by size GRG recovery with feed size distribution

4.4 Metallurgical results of campaign 2

The introduction of a rod mill in the grinding-B circuit prior to the second campaign facilitated testing at high throughputs from 13 t/h to 19 t/h at coarse top feed size, as shown in Table 16.

Table 16: Overall metallurgical results of campaign 2

Test #	Screen Size (mm)	Fluidiz. flowrate (m^3/hr)	G-force	Feed rate (t/hr)	Concentrate % GRG Rec.	Concentrate Grade Au, g/t	Tails GRG g/t	Tails non-GRG g/t	Feed gold g/t
1	3.5	4.5	60	13.3	62.9	17614	6.10	3.37	16.4
2	1.0	4.5	60	14.5	51.3	16003	6.66	2.93	13.7
3	1.0	4.1	40	13.9	47.8	12501	6.67	2.54	12.8
4	1.0	5.2	90	13.9	51.7	11944	5.76	2.66	11.9
6	3.5	2.3	40	18.3	45.7	14279	6.72	2.93	12.4
7	3.5	3.2	60	18.9	46.6	11680	5.27	2.51	9.9
8	3.5	5.2	90	17.4	48.4	11363	5.34	2.1	10.4
9	3.5	5.2	60	16.1	45.2	29066	9.51	4.2	17.3
10	3.5	4.1	40	16.2	54.0	20407	8.17	2.59	17.7
11	3.5	4.1	60	16.4	50.1	17241	8.02	2.56	16.0
13	3.5	5.2	40	16.5	49.3	16046	6.29	2.88	12.4
14	3.5	4.5	60	14.7	55.5	11918	5.48	2.88	12.3
15	3.5	4.5	60	15.4	46.4	12742	5.96	2.98	11.1
16	3.5	4.5	60	15.2	87.2	11819	0.79	3.15	6.2
5	1.0	4.5	60	14.3	61.0	54047	5.87	2.86	15.0
12	3.5	4.5	60	17.9	50.2	52523	6.41	2.8	12.9

In all 16 tests, 14 short and 2 long, were conducted. Overall recoveries ranged from 45% to 87%. An interesting observation is that the pilot KC CD12 is capable of achieving acceptable recoveries at feed rates higher than those of the manufacturer recommended, 8 to 12 t/h. This may stem from an incomplete understanding of performance scale up from a LKC to a full scale unit. GRG metallurgical balances for both the pilot test tail processed on LKC and overall pilot tests were generated. Detailed metallurgical balances are presented in Appendix 3 (Table 68 -Table 114).

4.4.1 Effect of feed rate as function feed top size

Figure 21 presents the effect of feed rate as function of feed top size on GRG recovery. All 16 tests were performed at high feed rates and most of them at coarse top size of 3.5 mm. Despite high feed rates (13 to 19 t/h), in excess to the earlier manufacturer recommended feed rates of 8-10 t/h (CD12 is now rated up to 20 t/h after this research work), GRG recoveries are consistent and range from 45% to 63%. Recoveries show a weak decreasing trend with increasing feed rates. It is unclear that a finer top size is beneficial for improving recovery, since fine top size tests are concentrated in a narrow feed rate range.

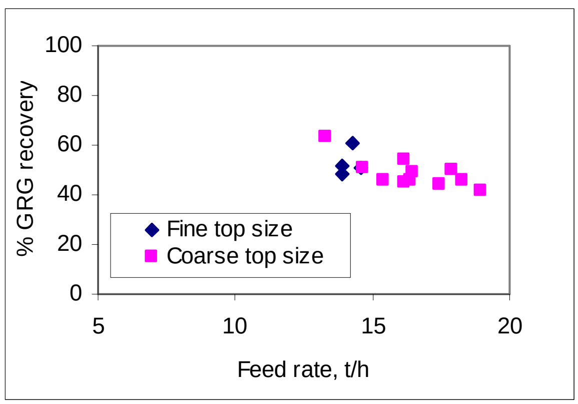

Figure 21: Effect of feed rate on GRG recovery as function of feed top size

4.4.2 Maximizing fine GRG recovery

Fine GRG recovery may be maximized by processing a fine feed material at a high feed rate. Two tests were conducted to explore this hypothesis. Also explored was the influence of increasing rotation speed on improvement of fines recovery. Test 2 and 4, both were conducted at a fine top size of 1.0 mm and high feed rate of 14.5 t/h and 13.9 t/h, respectively. Figure 22 shows the recoveries for these tests. Test 4 was performed at high rotating velocity of 90 Gs whereas Test 2 at 60 Gs. It can be seen that recovery decreases up to 75 µm but then increases for the fine size classes, 53 µm to -25 µm, which ranges from 40 and 60%.

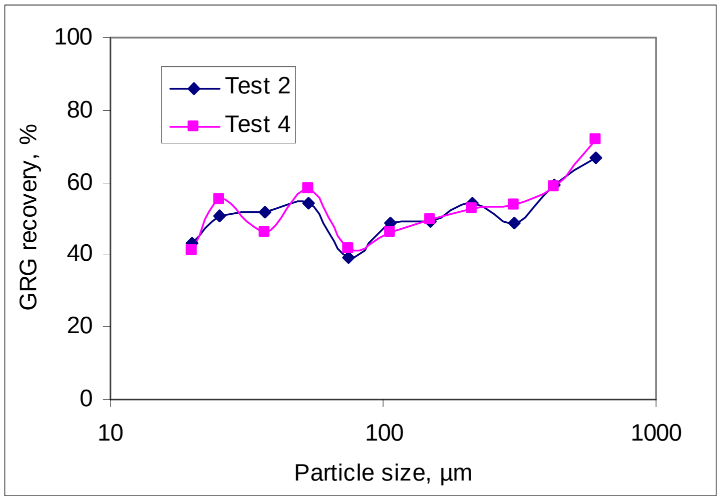

Figure 22: Effect of fine top size as a function of rotating velocity

4.4.3 Exploring the coarse feed size of PJV

Five tests, four in campaign 2 (Test 6, 7, 9 and 10) and test 19 from campaign 1, were tested to explore the impact of coarse top feed size. These five tests were performed at coarse top size of 3.5 mm. GRG recoveries for coarser particles, especially larger than 850 µm are not shown since gold in the coarser fractions from 1700 to 850 µm were combined mathematically in the 600 µm size class corresponding to the coarsest size class (600 µm) assayed for tailing for metallurgical balance (as discussed in sampling strategies for GRG, Chapter 3). Figure 23 presents the size by size GRG recoveries for tests 6, 7, 9, 10 and 19. GRG recoveries from these tests produced lower recoveries ranging from 40% to 54%. Recoveries for coarser fractions, 600 to 106 µm, are lowest for test 19 due to the coarse grind during campaign 1. This is reflected in tailing analysis shown below.

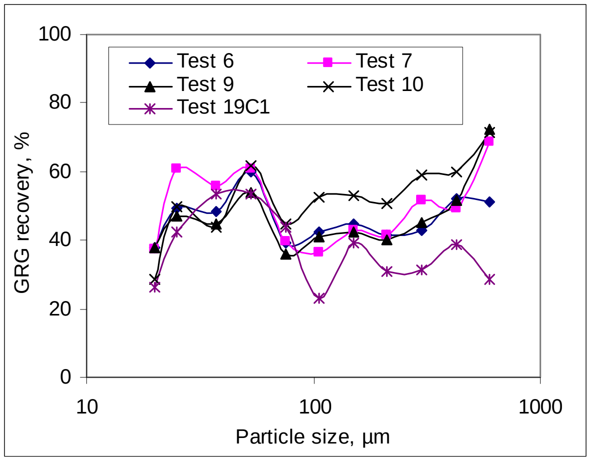

Figure 23: Effect of coarse top size on size by size recovery

Figure 24 presents size by size GRG losses in the tailings. Test 19 produced lowest tailing losses in all size fractions, which was performed at a feed rate of 13 t/h. Fine losses are maximum,12 g/t to 32 g/t, especially from 106 to 25 µm, for tests 9 and 10 that were processed at mid fluidization flow rates and low rotating velocity, respectively.

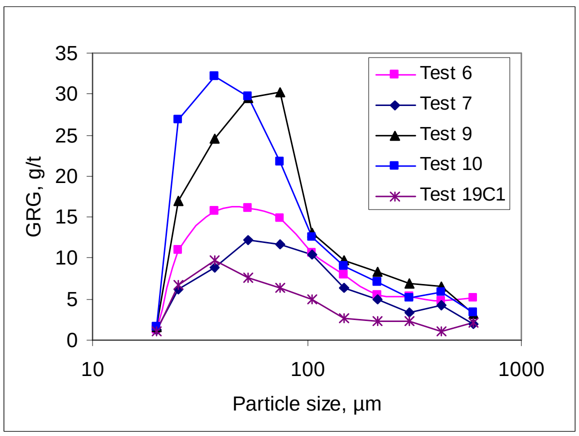

Figure 24: Size by size GRG losses in pilot test tails

4.4.4 Effect of high percent solids on GRG recovery

Two tests were conducted at high percent solids, test 14 (50% solids) and test 16 (52%), while keeping other variables the same. The results are presented in Figure 25. The result of test 16 seems encouraging; despite high feed rate (15 t/h) and coarse top size

(3.5 mm), recovery of all sizes range from 68 to 94% with an overall recovery of 87%, the highest among the tests of campaign 2. However, result of test 14 does not support the argument despite similar operating conditions. Further testing at high percent solids is needed to confirm the benefit.

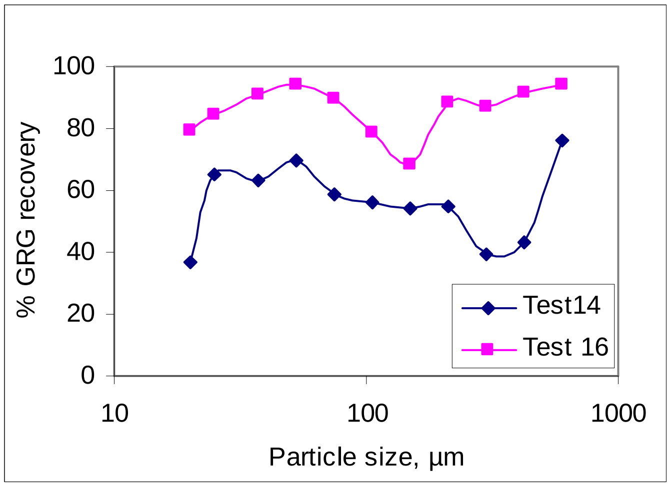

Figure 25: Effect high % solids on size by size GRG recovery

4.5 Concentrate bed erosion tests-campaign 2

To measure the extent of concentrate bed erosion for the operating Knelson concentrators at Dome mine, two tests, 5 and 12, were performed covering the extreme conditions. The results are presented in Tables 17 and 18. Detailed metallurgical balance of the LKC of pilot test feed, tails and pilot tests are presented in Appendix 2 (Table 97 - Table 114).

Table 17: Metallurgical performance of pilot Knelson concentrator for Test 5

Pilot KC	(0-15 min)			(15-30 min)			(30-60 min)			(60-90min)			Overall		
	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG
Feed, g/t	16.0	13.2	2.7	14.5	12.2	2.3	12.6	10.4	2.3	13.0	10.4	2.6	13.6	11.2	2.4
Tailing, g/t	9.4	6.4	2.9	9.6	6.5	3.2	8.3	5.7	2.6	8.4	5.4	3.0	8.7	5.9	2.9
Recovery,%	41.3	51.3	-	33.6	47.1	-	34.6	45.0	-	35.4	48.2	-	35.9	47.7	-

Table 18: Metallurgical performance of the pilot Knelson concentrator for Test 12

Pilot KC	(0-15 min)			(15-30 min)			(30-60 min)			(60-90min)			Overall		
	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG	Total Gold	GRG	Non-GRG
Feed, g/t	15.6	11.6	4.0	13.1	10.2	2.9	13.7	10.8	3.0	14.0	11.5	2.5	14.0	11.6	2.5
Tailing, g/t	9.3	6.7	2.6	9.7	6.5	3.2	8.8	6.2	2.6	9.4	6.4	3.0	9.2	6.4	2.8
Recovery,%	40.6	42.4	-	25.9	36.1	-	36.1	42.3	-	33.0	44.6	-	34.4	44.6	-

Test 5 represents conditions of low feed rate and fine top size whereas test 12 represents high feed rate and coarse top size. Both tests show some bed erosion especially during the second and third periods of recovery cycle.

Overall results of concentrate bed erosion tests

Overall results of the concentrate bed erosion tests are presented in Table 19. During the first campaign feed rates could not be changed because of the coarse feed size to the Knelson concentrators. Because of this, the three tests did not show severe bed erosion for the top sizes of 1.0 mm and 2.0mm, however for the coarse top size, 3.5 mm some bed erosion was observed during the second and third period of the cycle time (Figure 26). The tests conducted during the second campaign have shown bed erosion at the beginning of the cycle time and the overall recoveries for the second campaign are low despite higher head grades. One important variable responsible for bed erosion in Knelson concentrators is the presence high density gangues having ore density of 4.0 g/cm^3.

Table 19: Result of the concentrate bed erosion tests

Test number	Feed rate t/h	Feed top size mm	Feed grade g/t	Overall recovery, %
11	7.0	1.0	16.83	83.72
15	8.0	2.0	8.70	75.42
18	8.1	3.5	8.03	60.79
5	15.0	1.0	15.96	47.71
12	17.0	3.5	15.62	44.59

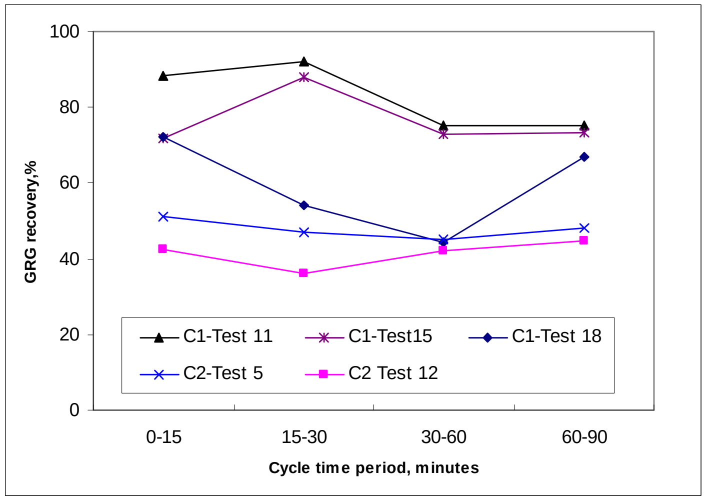

Figure 26: GRG recoveries as a function of cycle time

For Knelson concentrators, the presence of high levels of sulphides in the ore can produce a phenomena referred to as ‘concentrate bed erosion’ whereby gold already concentrated on the surface of riffles of the concentrating cone is removed by the scouring action of the high density gangue particles such as pyrite. Thus, the concentration of high specific gravity gangue minerals in the ore dictates the gold concentration mechanism. For Dome ores, sulphides constitute a small percentage, 2-3% (Scales, 1989), offering small or minor erosion rates even at (two times the cycle time of 45 minutes) high recovery cycle time of 90 minutes. This supports the idea of screening the Knelson feed at coarser top size to maximize throughput at shorter cycles. It has been reported for the operating Knelson concentrators in a regrind application at Kemess mine, recovery cycle time of 5 minutes were adopted to minimize the effect of high pyrite gangue (Froehling et al., 2007). The effect of concentrate bed erosion is more pronounced on fine gold, as reported in the Kemess regrind application.

4.6 Overall GRG recovery for the tests of campaign 2

GRG recoveries of 16 tests are presented in Figure 27. It can be seen that the size by size recoveries of test 16, performed at high feed percent solids (52%), had produced highest recoveries among the tests.

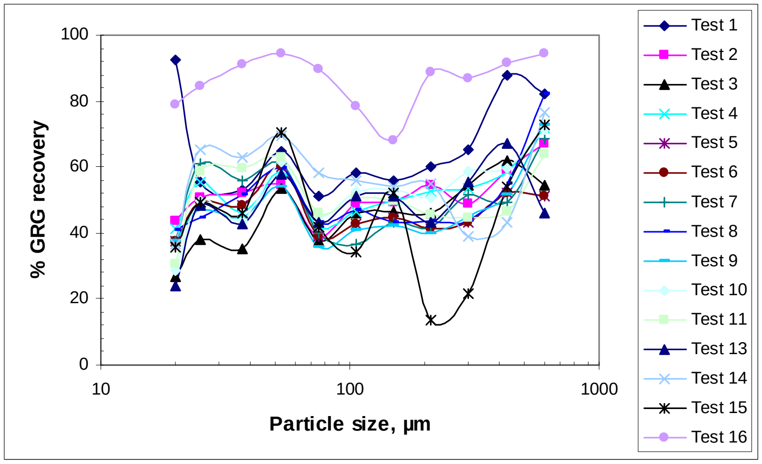

Figure 27: Size by size GRG recoveries for the 16 tests

Figure 28 shows the averaged GRG recovery curve along with the averaged feed size distribution curve of the corresponding tests. Despite finer feed to the Knelsons, the shape of the recovery curve is similar to the recovery curve of campaign 1.

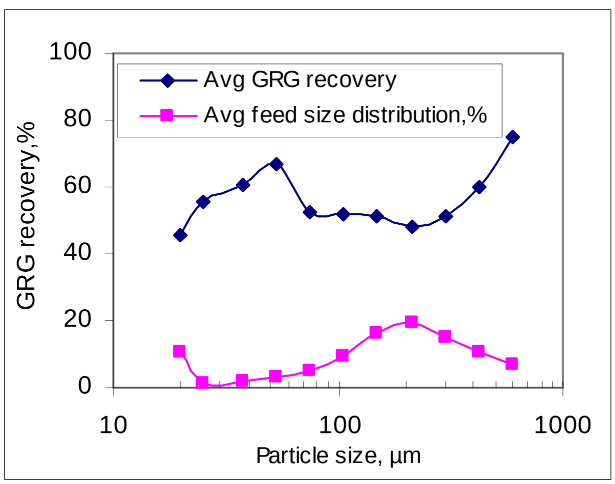

Figure 28: Average size by size GRG recovery for the 16 tests

Figure 29 shows the overall recovery for all the thirty one tests as function of feed rate, for the three top size chosen. From the data it is obvious that feed rate explains much of the variations in GRG recovery, top size also being a contributing factor. The benefit of finer top size is not evident, since recoveries are lower at higher feed rates. Feed rates of 7-13 t/h coupled with coarse top size, 3.5 mm produced low recoveries especially for the tests performed in campaign 1.

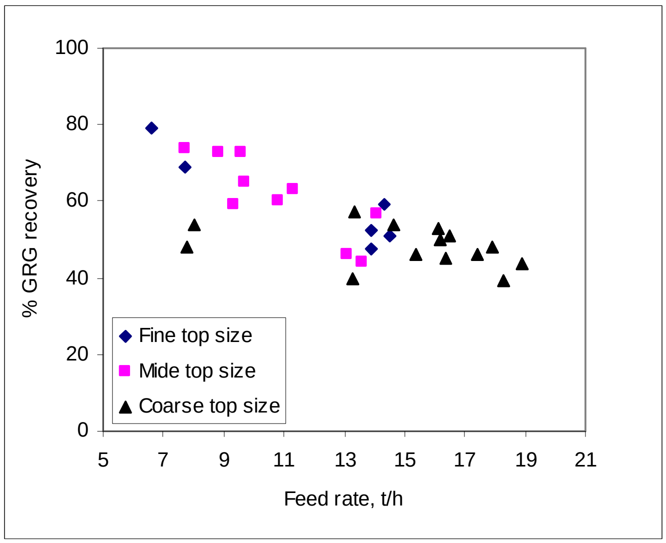

Figure 29: Effect of feed rate as a function of top size

The averaged GRG recovery curves of campaign 1 (C1) and campaign 2 (C2) are plotted along with their feed size distributions in Figure 30. The similarity between the curves is striking, despite finer feed during the second campaign. Feed rates of campaign 1 tests ranged from 6 t/h to 14 t/h, whereas the feed rates of the campaign 2 are significantly higher, from 13 t/h 19 t/h, with most of the tests, 12 out of 16, performed at the coarse top size. Overall low recovery during campaign 2 may be the effect of high feed rates. Lower recoveries of the finer size fractions, 75 µm to 20 µm may be due to the combined effect of high feed rate and coarse top size. The feed size distributions of the two campaigns are identical, the shapes of the curves strikingly similar.

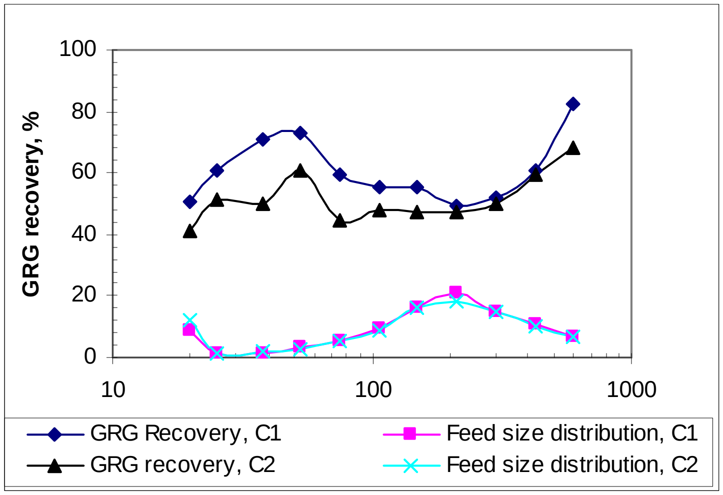

Figure 30: Comparison of size by size GRG recoveries of the two campaigns

4.7 Analysis of the unusual GRG recovery curves

To analyze the unusual recovery performance, two full scale Knelson performances have been used; a KC CD20 Knelson concentrator, Golden Giant, Canada and a KC CD30 Knelson concentrator, Marvel Loch, Australia. Figure 31 shows the size by size performance of a KC CD20 Knelson concentrator operated at Golden Giant Mine, Canada (Charest, 2001). Fluidization flow rates and G-force are presented with feed size distribution (S.D.) in the legend. The feed size distribution has a peak at the 75-106 µm size class. Size by size recoveries decrease monotonically with decreasing particle size, except for the -25 µm size, since the LKC used to measure GRG content in the tailing stream did not recover all of the GRG below 25 µm. GRG recoveries at different fluidization flow rate and G-force have a decreasing trend with decreasing gold particle size.

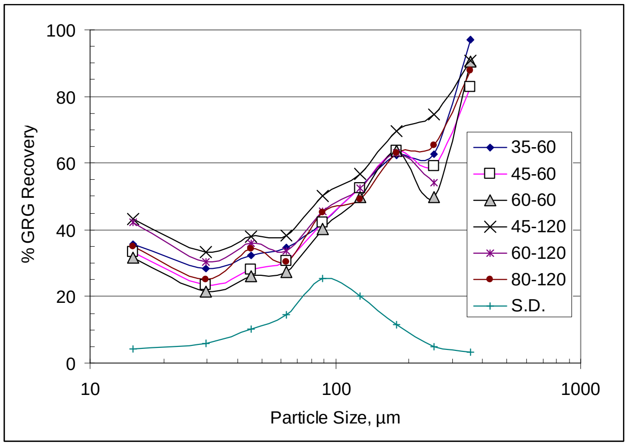

Figure 31: GRG recoveries for the KC CD20 Knelson concentrator (Laplante, 2005)

It is apparent from Figure 31 that there is no significant impact of either fluidization flow rate or G force on the shape of the recovery curves, something similar suggested by the pilot Knelson test data as seen in Figure 30.

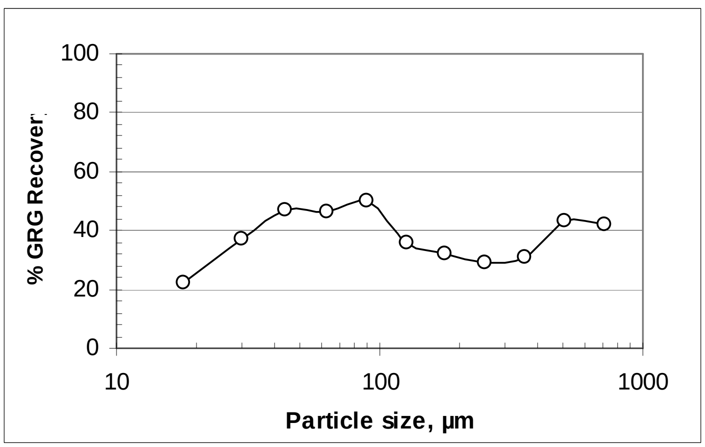

Figure 32: Size by size GRG recovery for KCCD30 (Laplante, 2005)

Figure 32 presents size by size GRG recovery for KC CD30 Knelson concentrator, Marvel Loch Plant, Australia (Laplante, 2005). It can be seen that the shape of the recovery curve is similar to the pilot tests curve.

The GRG recovery curves for Dome mill pilot plant (KC CD12) and Marvel Loch (KC CD30) Knelson concentrators are compared in Figure 33 (Koppalkar and Laplante 2007). The similarity between these curves is striking. These two curves display an unusual shape. Both these curves have a similar feed size distribution, which is definitely coarser than that of Golden Giant feed size.

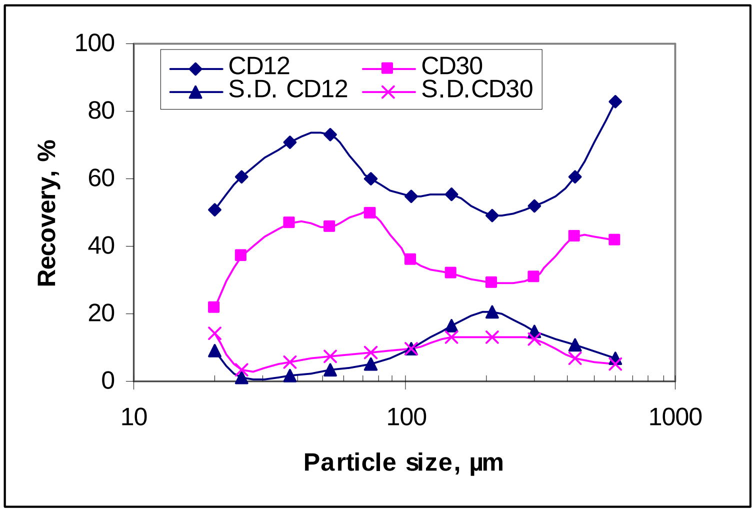

Figure 33: Comparison of recoveries of KC CD12 with the KC CD 30, Marvel Loch

These curves also suggest that operating conditions, like feed rate, rotating velocity, fluidization water flow and screen aperture size, have little impact on the shape of the recovery curve compared to the feed size distribution. A coarser feed size distribution, similar to the pilot test data, will recover particles between 25 and 106 µm but would impact negatively on the recovery between 106 and 425 µm. On the other hand, a finer feed like the Golden Giant would produce a monotonically decreasing recovery with decreasing particle size. The low recovery zone at intermediate sizes would be linked to the natural resistance to flow or percolation, which is significant at a particle size where the gangue is most abundant. The flowing slurry in the Knelson cone could be thought as a dynamic screen with openings roughly of the order of magnitude of the dominant particle size.

Other researchers have also observed similar recovery troughs as observed in this work. Ling (1998) conducted tests on a 3-in variable speed Knelson concentrator and observed a dip in recovery at intermediate sizes. He linked it to the higher ratio of diameter of intermediate size tungsten to gangue particles compared to the diameters ratio of finer tungsten to gangue particles and hence the intermediate tungsten has a lower ability to percolate through the small voids of a relatively compact separation zone. Moreover, intermediate size tungsten particles, unlike coarser tungsten particles do not posses mass large enough to intrude forcibly into the separation zone. Laplante et al., (1996) postulated a particle shape effect to explain the recovery trough. An increase in feed density decreases the porosity of the bed, and makes the percolation of fine flakes (75-300 µm) more difficult than fine spheres (-37 µm), which do not experience any percolation problems. Similar recovery troughs observed in the magnetite and tungsten-based test work (Buonvino, 1993; Ling 1998; Ancia et al., 1997) ruled out the particle shape effect (magnetite and tungsten are not lamellar). The present results do not support the effect of particle shape and suggest particle size as the main cause of the recovery trough.

Based on the observation and data analysis from the two industrial data as above, a particle size hypothesis is now presented.
The hypothesis: Size by size GRG recoveries are Knelson feed size distribution dependent.

Assumptions:

1. Finer feed size (P_{80} <150 µm) distribution produces decreasing recoveries with decreasing gold particle size.
2. Coarser feed size (P_{80} >150 µm) distribution produces unusual shape (bi-modal) of size by size recovery.

The proposed particle size effect hypothesis will now be examined with the performance data (Table 20) from different operating Knelson concentrators.

Table 20 : Additional data sets for the proposed particle size hypothesis

Source (Plant)	Knelson unit	Type of feed
Aurbel	KC CD30	Coarse
East Malartic	KC CD30	Fine
Site 1	KC CD30	Coarse
Site 2	KC CD30	Coarse
Site 3A, 3B	KC CD30	Coarse
Kemess Mine	KC CD30	Fine
Site 5	KC CD30	Coarse

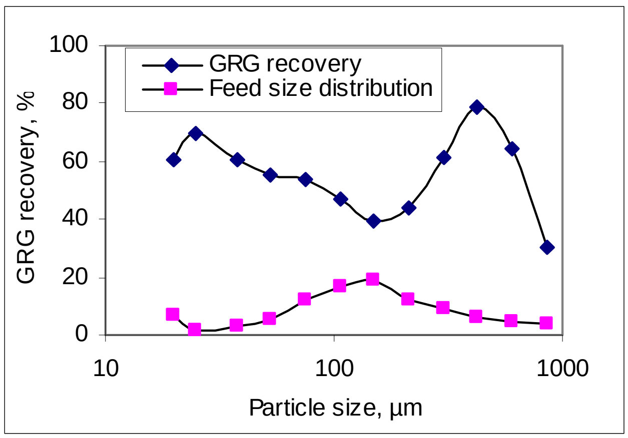

Figure 34: Size by size GRG recovery at Aurbel (Vincent, 1997)

Figure 34 shows size by size GRG for the KC CD30 Knelson concentrators at Aurbel, Canada. Size distribution data are also presented. Mode of the feed size distribution is at 150-212 µm with modal distribution of 20%, i.e., 20% of particle mass is at 150-212 µm size class, offering resistance to the flow of gold particles. Thus recovery of gold particles between 106 and 212 µm sizes is low. A low recovery zone corresponding to the mode of the feed can be seen. Because of the coarse size distribution of the feed, the size by size recovery has the unusual shape, as seen in the pilot test data.

Figure 35 presents the performance of a KC CD30 unit at the East Malrtic plant (Vincent, 1997), Canada. The feed size distribution is fine with a mode at 75-106 µm size class, with 25% of the feed mass between 75-106 µm, minimizing the recoverability of the finer gold particles. Hence we see a monotonically decreasing gold recovery with decreasing particle size.

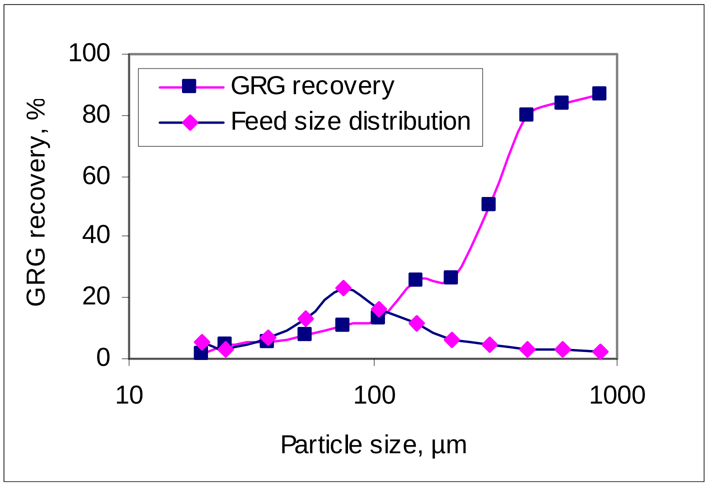

Figure 35: Size by size GRG recovery at East Malrtic (Vincent, 1997)

The names of the following plant sites are not disclosed to maintain the requested confidentiality. Figure 36 shows size by size GRG recoveries for KC CD30 Knelson concentrator at site 1. Mode of the feed size distribution is between 106 and 212 µm with 20% of feed mass between those sizes. There is dip in recovery, mid size classes (75-200 µm) exhibit no recovery, corresponding to the mode of the coarse feed size distribution.

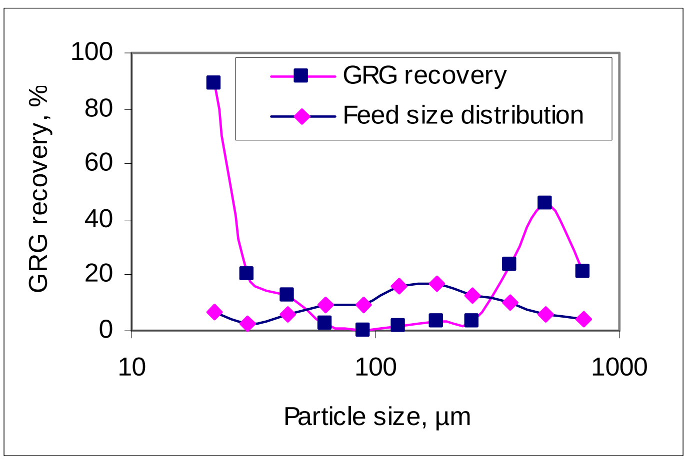

Figure 36: Size by size GRG recovery at site 1

Figure 37 presents the GRG recovery data from site 2. Mode of the feed is at 106-212 size with about 22% of feed mass offers resistance to the flow of gold particles to produce a shape that has a trough at the intermediate size fractions.

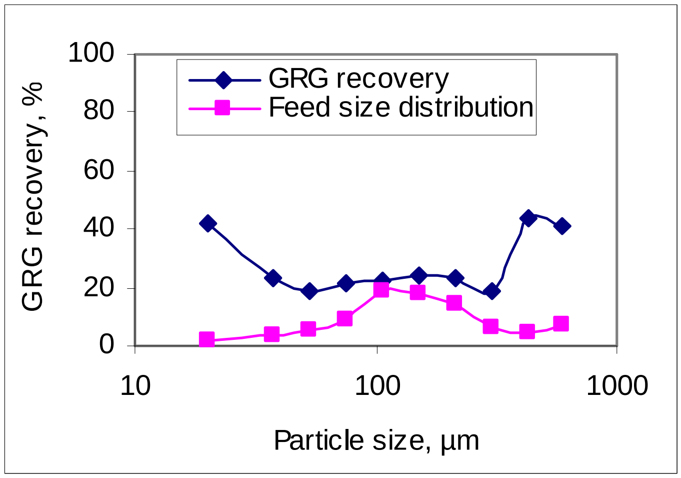

Figure 37: Size by size GRG recovery at site 2

Figure 38 and 39 show two GRG recovery data for site 3 (A, B). Both dip in recovery at the mode (300-425 µm) of coarse feed size distribution. 20% of the feed particle mass is at 300-425 µm offering resistance to the recovery of intermediate size gold particles.

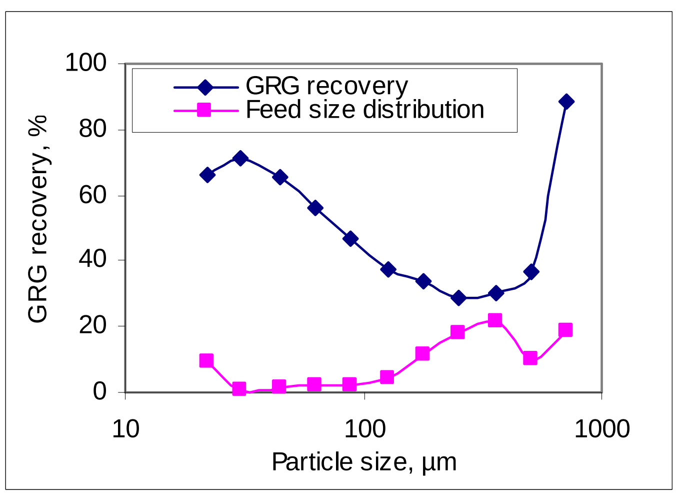

Figure 38: Size by size GRG recovery at site 3A

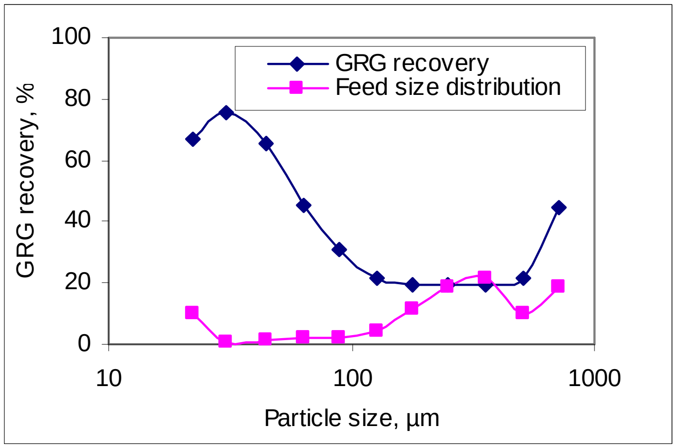

Figure 39: Size by size GRG recovery at site 3B

Data for a KC CD30 Knelson concentrator, from a regrind application at Kemess mine, Northgate Minerals Corporation, BC, Canada is presented in Figures 40, 41 and 42. The three data sets produced consistent performance. Since the data represents fine regrind application, the size by size GRG recovery curve and its feed size curve have shifted to the finer side, i.e., <212 µm. However, a low recovery zone corresponding to the middle part of the feed size distribution between 53 and 75 µm is seen, with about 30% of the particle mass offering resistance to the flow of gold particles at intermediate sizes in three data sets confirming the particle size hypothesis.

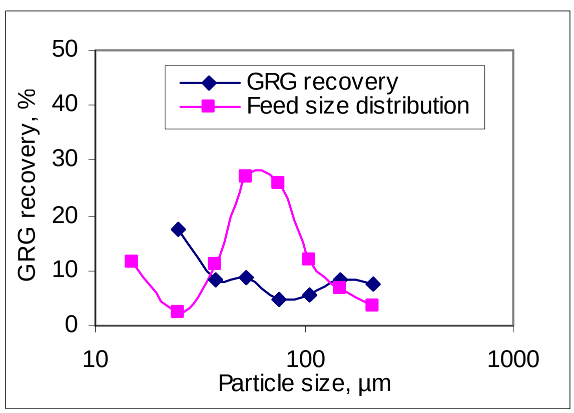

Figure 40: Size by size GRG recovery-1 at Kemess mine

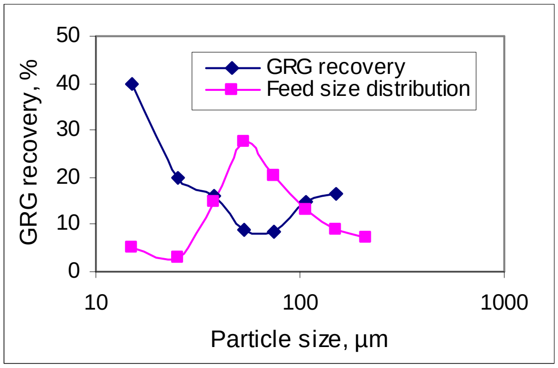

Figure 41: Size by size GRG recovery-2 at Kemess mine

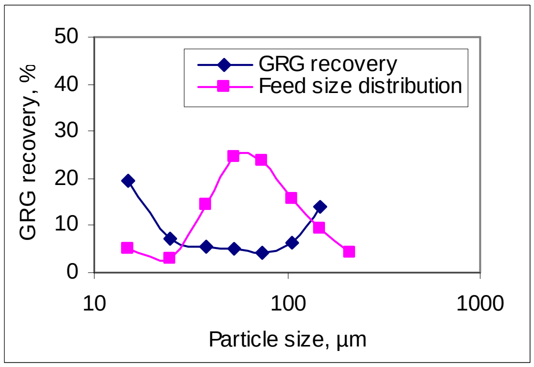

Figure 42: Size by size GRG recovery-3 at Kemess mine

Figure 43 presents yet another unusual recovery curve for the Knelson concentrator at site 5 and has a low recovery zone at the intermediate size classes. The most abundant classes of the feed size distribution exhibit a dip in the recovery.

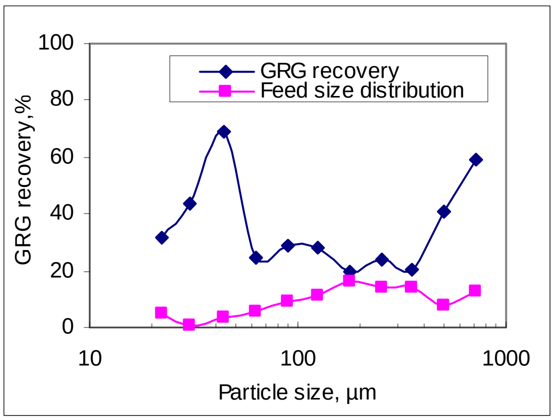

Figure 43: Size by size GRG recovery at site 5

From the analysis of these industrial data, it is clear that the shape of the recovery curve is linked to the size distribution to the gravity concentration equipment. This finding, the particle size effect, is useful for the simulation of the Knelson units. Simulations are performed using the typical Knelson recovery curve- decreasing recovery with decreasing gold particle size, for estimating gravity recovery and it was thought that the nature of the curve had no impact on the estimate of gravity recovery (Laplante, 2005).

The current recovery models: gravity recovery model developed by McGill gold gravity research group, Knelson Concentrators and Web based simulator developed under AMIRA P420B use the fine curve- 'decreasing gold recovery with decreasing gold particle size'. For high throughput applications, Knelson Concentrators, use the de-rated fine curve, as shown in Figure 44.

This research has shown that the feed size distribution affects size by size recoveries of the Knelson concentrator. Now with this finding, for gravity recovery simulation, either the fine or coarse recovery curve (Figure 44) will be used depending on the nature of the feed to gravity circuit. For example, for a target grind size, P_{80} of 105 µm, the fine curve and for a coarse grind, P_{80} of 175 µm, the coarse curve could be used respectively.

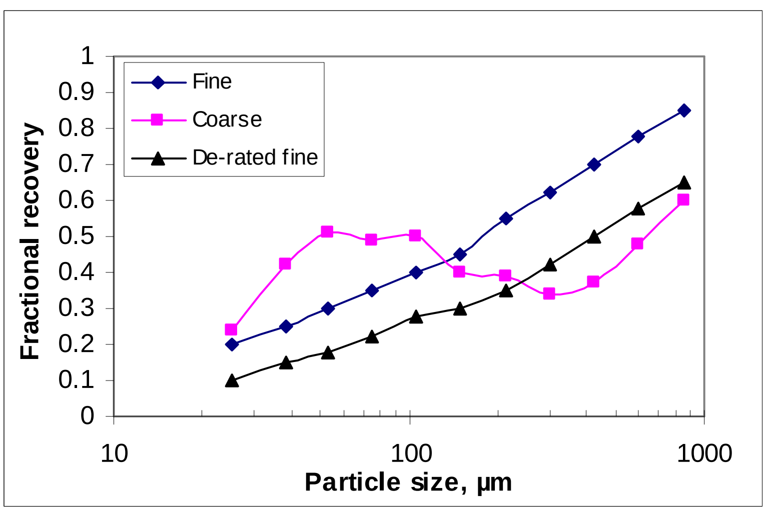

Figure 44: Knelson recovery data used for simulation of gravity recovery

4.8 Modeling size by size GRG recovery

An empirical relationship linking the feed size distribution and specific feed rate to the GRG recovery was developed. Averaged data from all 31 pilot CD12 tests (Dome mine) was considered for modeling since the size by size recovery from individual test showed significant scatter. Feed rate to the tests was converted into specific feed rates. The relationship yielded the following regression. The recovery for size fraction, Y_i is calculated as:

$$Y_i = 61.5 + 0.028 * size - 2.48 * Specific\ feedrate + 1.34 * feed\ wt\% \tag{4.3}$$

where Yi: Recovery of size fraction i (%)

Size: size fraction i (microns)

Specific feed rate: $t/h/m^2$

The regression has a significance of 99% and a lack of fit of 5% as a result of the scatter, the correlation coefficient is low at 0.8.

Actual and calculated size by size recoveries for all the pilot Knelson concentrator tests are compared in Figure 45.

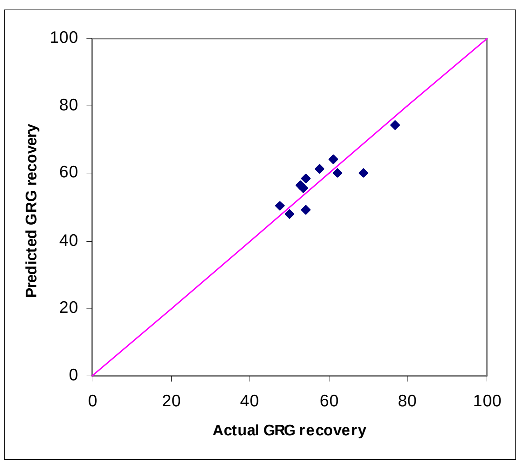

Figure 45: Comparison of actual and predicted GRG recovery

Chapter 5 Settling of dense particles in the gravitational field

5.1 Introduction

Settling of dense particles into the bulk material bed is a common phenomenon in gravity processing. It takes place in all gravity devices whether they be a jig, sluice, shaking table or centrifugal concentrator. The phenomenon of settling of dense particles can also be observed in unit operations like screening, grinding, feeding, mixing and during transportation of materials either wet or dry. For the Knelson concentrator, centrifugal settling of gold into the concentrate bed is particularly important because it largely determines the performance. The fundamentals of settling in the gravitational field have many similarities to centrifugal settling. Gravitational settling is more easily observed and measured than centrifugal settling since the movement of particles in a bulk bed can be created in a stationary transparent tube. To gain some insight into the settling behavior of dense particles into the inner bowl of a KC, experiments on the settling of dense particles in the gravitational field were conducted. A simple binary mineral system of gold and silicates was mimicked using tungsten as a surrogate for gold and silica representing the gangue material.

5.2 Experimental methodology

5.2.1 Materials and apparatus

Gray polyhedral tungsten particles with a tungsten content of 99.9% and a density of 19.3 g/cm^3, obtained from GTE Sylvania Products Corporation, U.S.A, was used to mimic gold. The sample was screened into size fractions. Appendix 3 presents images of the sized tungsten particles. From these photographs it can be seen that the particles are irregular in shape and have submetallic lustre. Silica sand with a density of 2.65 g/cm^3

was used to represent a low density gangue material. Prior to testing, it was cleaned using a hand magnet to remove magnetic and other heavy impurities.

The apparatus used for the settling tests was fabricated at McGill University. It consists of a cylindrical vertical settling column made of Plexiglas. The design is based on the original design described by Couderc (1985). The equipment fabricated at McGill University was further modified such that the extraction of the concentrate was easy and consistent. Figure 46 is a picture of the settling equipment (76 mm x 590 mm). It is composed of three sections, upper circumferential launder, middle cylindrical section and lower conical section filled with glass balls to stabilize the flow of water. A flange arrangement connects the lower cone with the middle cylindrical column. A distributor plate made of an evenly perforated Plexiglas plate covered by 38 μm screen was fixed on the lower conical section by a stainless steel ring so that the distributor together with the conical section can be taken out as a single unit.

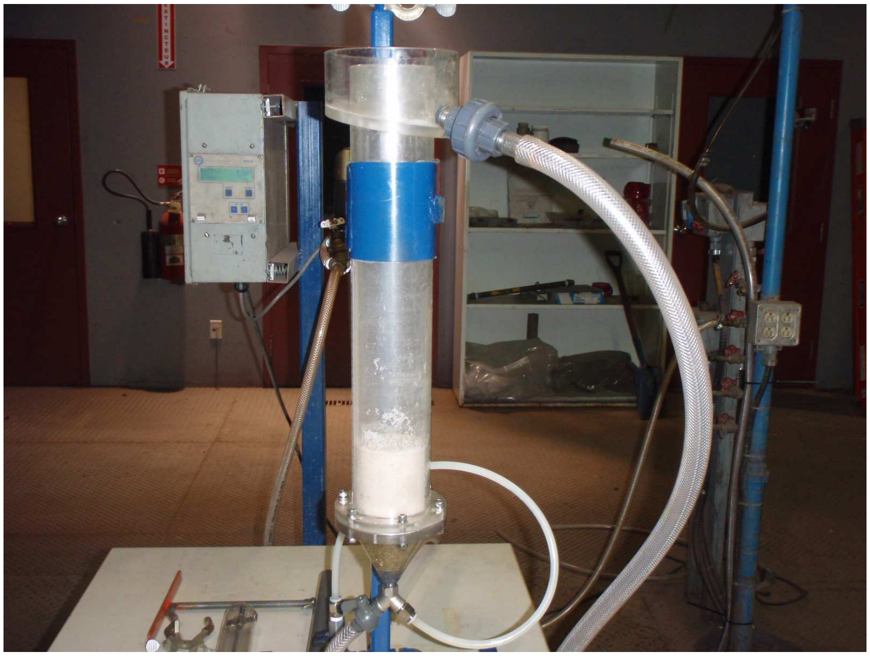

Figure 46: Settling test equipment

5.2.2 Testing methodology

At the beginning of each test the equipment was connected to a water line through a flow meter. Two hundred grams of silica of single size class (425-600 µm, 212-300 µm, 106-150 µm) was added to the column and fluidization water was introduced at the bottom of the column at high flow rate (4.0 l/m) for 2 minutes to remove any entrapped air bubbles. Fluidization rate was adjusted to the desired reading. Five grams of tungsten was loaded in the feeding tube with water. Figure 47 is an image of the feeding tube. It has a conical rubber cork which seals the bottom of the tube until the piston is pressed. The piston shaft is spring loaded to facilitate instantaneous release of dense particles. The feeding tube was introduced into the settling column and was positioned 4.0-4.50 cm above the surface of the fluidized gangue bed. Dense particles were then introduced by pressing the spring loaded piston for instantaneous release of all particles. Time was clocked the moment the dense particles touched the gangue bed and the test was run for 20 seconds. The test was stopped by closing the fluidization valve. Water in the column was slowly discharged by opening the bottom valve.

Figure 47: Feeding tube arrangement for introducing the dense particles

Picture A

Picture B

Picture C

Figure 48: Sequence of extraction of the settled bed (A, B and C)

Figure 48 shows three pictures, which depict the sequence of extraction of the settled bed. After the water is drained off from the drain valve at the bottom, the PVC piston (picture A) is gently introduced into the settling column up to the top of the settled bed and the column placed upside down, as shown in picture B. The PVC piston is machined to the inner diameter of the settling equipment for a tight fit and is fitted with a soft rubber ring at the bottom for proper sealing of the settled bed. The six flange bolts were removed to take out the conical section. The settled bed of known height (picture C) was then gently pushed by a jack screw (as shown in picture B- inserted in the inversed column) fitted on the hollow shaft of the piston. The material was collected in three portions and each portion was then subjected to panning to extract the dense particles. Panning was preferred over use of the Mozley table to minimize the time required for the separation of heavy particles from the gangue.

5.3 Results and discussion

5.3.1 Relation between superficial velocity and the gangue bed

The relation between the height of gangue bed and fluid velocity was estimated and the results are presented in Figure 49. The relationship between height of the gangue bed and the superficial velocity for the two sizes tested, coarse silica 600 µm and fine silica 212 µm is shown. It can be seen that the height of the gangue bed increases as the fluid velocity is increased. However, the expansion of the gangue bed is different for fine and coarse beds; the expansion for the fine bed varies from 8.5 cm to 12 cm, whereas the expansion is from 9.0 cm to 10.5 cm for the coarse bed. Generally, fine gangue beds could be more easily fluidized than coarse gangue beds.

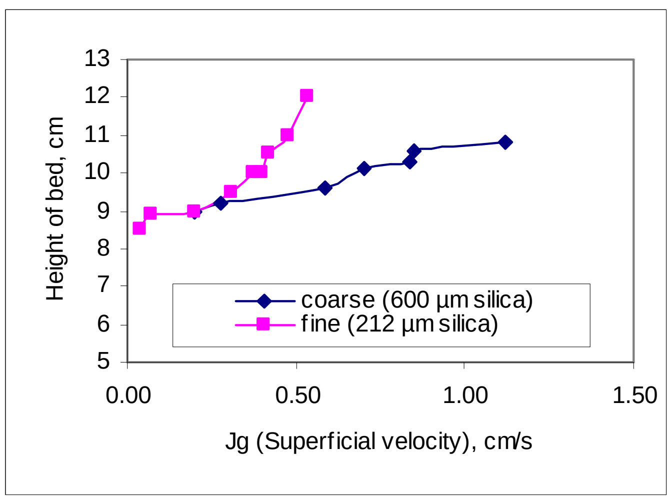

Figure 49: Height of the gangue bed as function of fluid velocity

Bed voidage is a function of bed expansion. Fractional voidage (φ) of the particle bed is calculated as,

$$\varphi = \frac{V_b - V_s}{V_b} \tag{7.1}$$

where V_s is the volume of solids, V_b is the volume of the bed, i.e., volume of water plus solids. Fractional voidage for the coarse and fine gangue beds was calculated as a function of superficial fluid velocity.

Figure 50 shows the relationship. The fractional voidage of fine gangue is more easily increased compared to the coarse bed. The fractional voidage for the coarse gangue was 0.02 at a fluid flow of 0.25 cm/s, whereas at the same fluid flow the fine gangue bed had a fractional voidage of 0.12. These curves do not start at the origin since there will be minimum voidage even at zero fluid velocity.

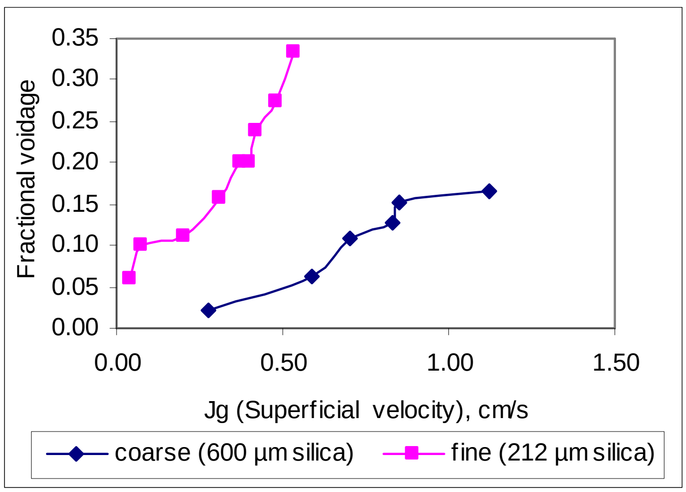

Figure 50: Relation between voidage of the gangue bed and fluid velocity

5.3.2 Effect of particle size on the settling of dense particles

Settling of dense particles in the coarse gangue bed

Figure 51 presents the recovery of tungsten for the coarse silica bed of 425-600 µm. Tungsten percolated well at a fluid velocity of 1.99 cm/s (voidage of 0.5) for the coarser fractions, but the recovery of the finer sizes, 38, 25 and 20 µm, drops as the settling velocities of these sizes are less than the fluid velocity, this coupled with the low voidage. Table 21 presents the settling velocities and Figure 55 depicts the graphical representation. High tungsten recovery of the coarser fractions is mainly related to the low density of the gangue resulting in low resistance to the settling of tungsten particles. It can be seen that the recovery of coarse dense particles is high, and these tungsten particles were recovered by intruding the gangue bed because of their mass and momentum.

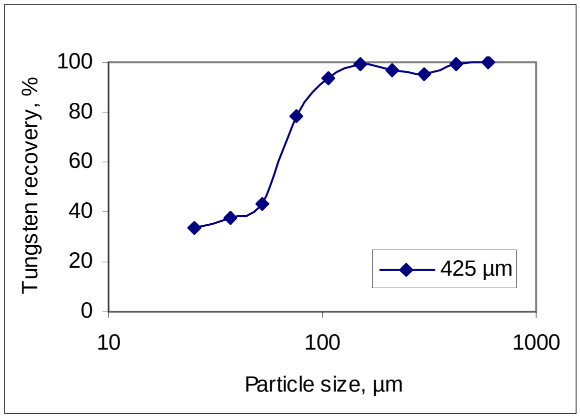

Figure 51: Tungsten recovery in a coarse gangue bed

Settling of dense particles in the fine gangue bed

Figure 52 shows the settling (recovery) of tungsten particles in the 212-300 µm gangue bed. The fluid velocity was 0.83 cm/s (voidage of 0.63). The low settling velocity of particles of the finer size class, 25 µm and 20 µm, 0.62 and 0.4 cm/s respectively resulted in low recovery despite a higher voidage.

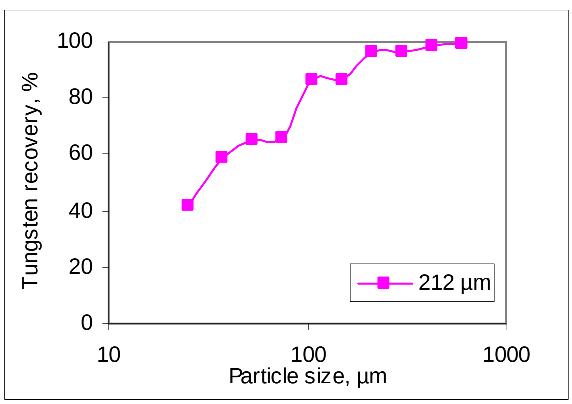

Figure 52: Tungsten recovery in a fine gangue bed

Recovery of tungsten for the finest gangue bed (106-212 µm) is presented in Figure 53. The gangue bed had a fractional voidage of 0.7 and fluid velocity of 0.32 cm/s. The recovery of finest size class is high at 60% as the settling velocity 0.42 cm/s, is higher than the fluid velocity, 0.32 cm/s, and secondly, the increase in voidage helps the percolation of these particles offering least resistance.

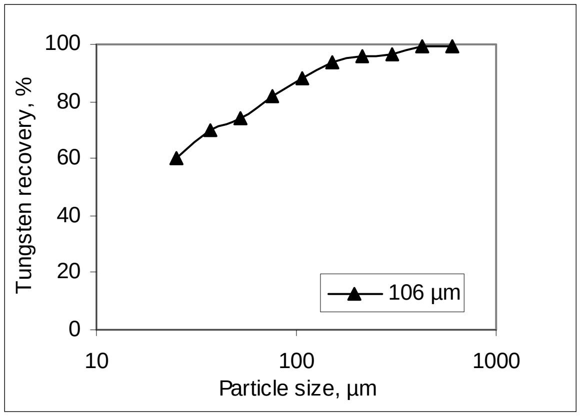

Figure 53: Tungsten recovery in a fine gangue bed

High tungsten recovery is mainly related to the low density and small particle size of the gangue bed resulting in low resistance to the settling of the tungsten particles. This indicates that the resistance of the gangue particles to the movement of tungsten is not only a function of voidage but also a function of size and density of the gangue. This is an important observation for the centrifugal settling of dense particles in the Knelson concentrator.

5.3.3 Particle settling velocity calculations

Settling velocities of particles under lamilar flow conditions were calculated using Stokes' equation for a particle settling under gravitational field.

$$v = \frac{gd^2(\rho_s - \rho_l)}{18\mu} \tag{5.1}$$

Where v= terminal velocity, cm/s

g= acceleration due gravity, 981 cm/s

d= particle diameter, cm

μ= viscosity of liquid, poise (viscosity of water at 20°C = 0.010 poise)

ρ_s , ρ_l = density of solid particle and liquid, respectively, g/cm^3

In order to determine whether the flow is lamilar, for Stokes' law to be valid, it is necessary to calculate the Reynolds Number. It is a dimensionless number that can be used to predict the transition from lamilar to turbulent flow for a variety of flow situations. In the case where a particle is moving through a fluid, the flow is lamilar and Stokes' Law is valid when Reynolds Number is less than about 0.2.

When Reynolds Number is higher than about 1000, Newton's Law is valid for settling of spherical particles:

$$v^2 = \frac{3gd(\rho_s - \rho_l)}{\rho_l} \tag{5.2}$$

However, for the most common sizes of particles encountered in mineral processing, the Reynolds number for settling under gravity in water falls into the transition region, where the flow is neither fully turbulent or fully lamilar. The resistance to flow changes non-linearly with velocity. In such cases, Newton-Rittinger equation is used to calculate settling velocities of particles (Kelly and Spottiswood, 1982).

$$v^2 = \frac{4}{3Q}\left(\frac{\rho_s - \rho_l}{\rho_l}\right)dg \tag{5.3}$$

Where Q is coefficient of resistance, which varies with Reynolds Number as shown in Figure 54.

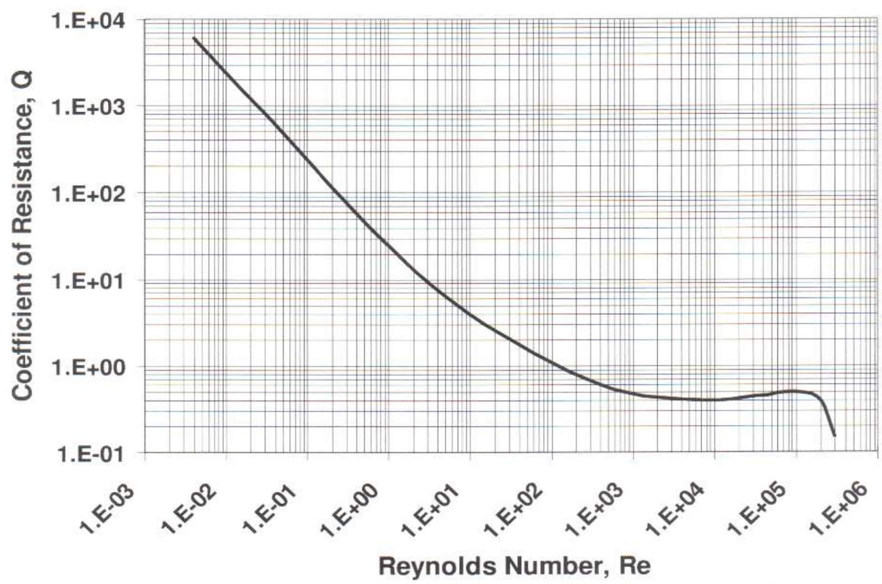

Figure 54: Variation of the coefficient of resistance as a function of Reynolds number

The Newton-Rittinger equation is solved using an iterative method, as:

1. Calculate terminal settling velocity using either Stokes' or Newton's equation.
2. Calculate the corresponding Reynolds number with that velocity.
3. Using Figure 54, calculate coefficient resistance (Q) that corresponds to the Reynolds number.
4. Substituting this value of Q into the Newton-Rittinger equation (5.3) for recalculating the settling velocity.
5. Repeating step3 and continue until the value of Q used in the equation (5.3) is same as found from Figure 54 when Reynolds number is calculated.

Table 21 shows the settling velocities calculated for tungsten and silica particles. The relationship between settling velocity and particle size is shown in Figure 55. Stokes' equation was used for tungsten particles of 25 and 20 µm as their Reynolds numbers are <0.2, whereas for all other sizes, settling velocities were calculated using Newton-Rittinger equation. Similarly for quartz particles, Stokes' equation was used for particles from 53 µm to 20 µm and Newton-Rittinger equation was used for calculating settling velocities.

Table 21: Settling velocities of particles, cm/s

Size	Tungsten		Silica	
µm	v, cm/s	Re_p	v, cm/s	Re_p
1700	97.28	1653.7	23.40	397.82
1180	75.18	887.1	17.49	206.33
850	59.48	505.6	12.36	105.10
600	45.11	270.6	8.65	51.92
425	33.16	140.9	5.91	25.12
300	23.45	70.3	3.62	10.86
212	16.02	34.0	2.66	5.63
150	10.94	16.4	1.55	2.33
106	6.88	7.3	0.90	0.96
75	4.40	3.3	0.46	0.35
53	2.45	1.3	0.25	0.13
38	1.36	0.5	0.13	0.05
25	0.62	0.2	0.06	0.01
20	0.40	0.1	0.04	0.01

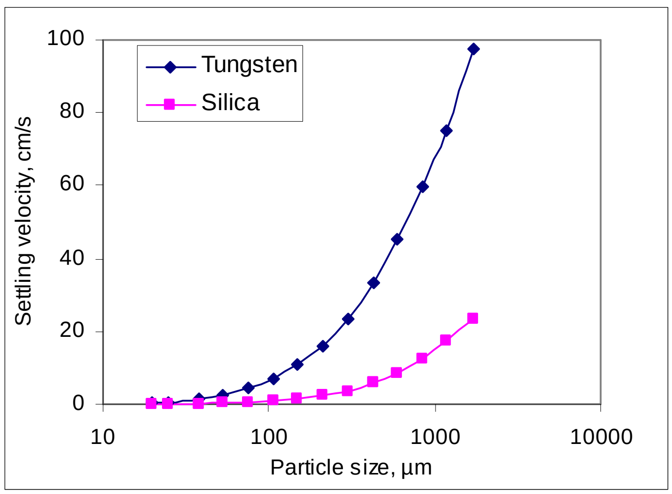

Figure 55: Settling velocity as a function of particle size

Two important observations useful for centrifugal settling in a Knelson concentrator can be summarized as:

- Coarse dense particles settling by gravity, in a low-density gangue, like silica, are recovered mainly by a mechanism of intrusion due their mass and momentum.
- Fine dense particles recovery is high for the fine gangue bed, due to the low resistance offered by the low density coupled with fine size of the gangue. This indicates that the resistance of the gangue particles to the movement of tungsten is not only a function of voidage but also a function of size and density of the gangue.

Chapter 6 General conclusions

6.1 Summary of the pilot test work

A pilot facility consisting of a KC CD12 Knelson concentrator, a vibrating screen and a sump-pump with an integrated control panel supplied by Knelson Concentrators was installed in one of the grinding circuits at Dome mine, Porcupine Joint Venture (PJV). The pilot plant was extensively sampled in two campaigns, the first prior to the grinding circuit modification and the second, after the commissioning of a rod mill in grinding-B circuit. The main bottleneck during campaign 1 was the coarse feed size (-6.0 mm) that resulted in frequent pipeline blockages. In all, 31 tests were conducted, 26 short recovery tests of 30 minutes and 5 long tests of 90-minute cycle. From the data generated, detailed metallurgical balances were produced for all the tests (Appendices 2 and 3).

Based on the test work and data generated, the main findings of this research work may be summarized as follows:

1. The KC CD12 Pilot Knelson tests yielded higher recoveries than expected for the feed rates employed. The feed rates maintained were significantly higher (6 -19 t/h) than the manufacturer recommended rates of 8 -10 t/h.
2. Recoveries were affected by feed rate and top feed particle size. Coarse top size affected GRG recovery.
3. Rotation speed and fluidization flow had no detectable impact on recovery. The effect of fluidization flow was consistent for extreme conditions.
4. The size-by-size GRG recovery for both the short and long cycle time shows a maximum between 25 μm to 75 μm and a second maximum at coarse size above 600 μm. This is atypical of Knelson performance, since recoveries commonly decrease with decreasing gold particle size.

5. The test work indicated that operating conditions including feed rate, rotation velocity, fluidization flow and screen aperture had minor impact on the shape of the recovery curve compared to the feed size distribution.
6. A particle size effect hypothesis was proposed and tested. The findings confirm that the shape of the recovery curve is dependent on the feed size distribution to the Knelson concentrator.
7. The effect of feed particle size needs to be incorporated in gravity recovery models for simulations.
8. The settling of dense particles in a fluidized gangue bed, in the gravitational field, was found dependent on the density and size of both gangue and dense particles and fluidization velocity. These findings are useful to explain the recovery mechanisms of fluidized centrifugal concentrators.

6.2 Claims for original contribution

1 The first comprehensive study of the effect of variables on the performance of a pilot KC CD12 relevant to full-scale operating practice was completed.

2 The first systematic industrial-scale concentrate bed erosion tests relevant to full scale operating practice was performed.

3 Gravity Recoverable Gold (GRG) recovery was shown to be dependent on feed size distribution.

4 The shape of the size-by-size recovery curve was linked for the first time to the feed size distribution: a coarse feed size distribution will produce a recovery-size curve that has low recoveries at intermediate particle sizes. However, when the feed size distribution is fine, the recovery will have a decreasing trend with decreasing particle size.

6.3 Suggestions for future work

1. The pilot test work produced recoveries comparatively higher than the full-scale unit. It appears that the size-by-size recoveries are dependent on the cone diameter.

The effect of cone diameter of the Knelson Concentrator on GRG recovery needs to be explored. This would prove useful for both basic understanding and industrial operations.

2. Effect of different cones (cone configurations) on size by size recoveries.
3. Scale up of Knelson performance from laboratory units to full-scale units still requires research.
4. Test work at high feed density, which has shown promising results, needs to be explored further to confirm the benefits.

References

Abols J.A and Grady P.M. Maximizing gravity recovery through the application of multiple gravity devices, Proceedings of the International Symposium on the Treatment of Gold Ores, 44th Annual Conference of Metallurgists, Calgary, pp.31-47, COM 2005

Ancia P., Frenay J., and Dandois P. Comparison of Knelson and Falcon Centrifugal Separators. Innovation in Physical Separation Technologies, Richard Mozley Symposium, Falmouth, United Kingdom, pp.53-62, 1997

Bridgwater J., Cook H. H., and Drahun J.A. Strain induced percolation, Powtech '83: Particle Technology, I. Chem. E. Symposium Series No.69, pp.171-191, 1983

Bagnold R.A. Experiments on a gravity-free dispersion of large solid spheres in a Newtonian fluid under shear, Proc. Royal Soc., London. Sec. A. 225, pp. 49-63, 1954

Banisi S. Gold's behaviour in grinding circuits, M.Eng thesis, McGill University, 1991

Banisi S., Laplante A.R., and Marois J. The Behavior of gold in Hemlo Mines Ltd Grinding circuit. CIM Bulletin, Vol 84, No.955, pp.72-78, Nov-Dec.1991

Bongarcon D.F. Geostatistical determination of sample variances in the sampling of broken gold ores, CIM Bulletin, Vol 84, No. 950, pp. 46-57, 1991

Burt R. Gravity Concentration Technology. Developments in Mineral Processing, Elsevier Science Publishers, Vol 5, pp.88, 1984

Burt R., Korinek G., Young S.R., Deveau C. Ultrafine Tantalum recovery strategies, Minerals Engineering, Vol 8, No.8, pp. 859-870, 1995

Burt R. The role of gravity concentration in modern processing plants, Minerals Engineering, Vol 12, No.11, pp 1291-1300, 1999

Buonvino M. A study of the Falcon concentrator. M. Eng thesis, McGill University, 1993

Chan B.S.K, Mozley R.H., and Childs G.J.C. Extended trials with the high tonnage Multi-Gravity Separator, Minerals Engineering, Vol 4, No.3/4, pp 489-486, 1991

Charest A. Performance of Knelson XD 20 concentrator at Golden Giant mine under different operating conditions, research project 306-410B, McGill University, 2001

Clarkson R. The use of radiotracers to locate and eliminate gold traps from grinding circuits in gold and base metal mines. Proceedings-35th Annual Meeting of Canadian Mineral Processors, Paper17, Ottawa, 2003

Cordingley M.G. MGS developments and strategies in fine gravity separation techniques. Innovation in Physical Separation Technologies, Falmouth, United Kingdom, IMM. pp. 75-82, 1997

Courdec J.P Incipient Fluidization and Particulate Systems, Fluidization, second edition, edited by Davidson, J.F, Clift R, and Harrison D. Academic press, London, Chapter 1, pp.1-30, 1985

Coulson J.M., Richardson J.F., Chemical Engineering, fourth edition, Pregamon press, Vol 2, pp. 174-177, 1990

Coutler T., Subasinghe G.K.N. A mechanistic approach to modeling Knelson concentrators, Minerals Engineering, Vol 18, pp.9-17, 2005

Cloutt B. Gravity concentration at W.M.C's St. Ives Gold Mines, Randol Gold Forum, Proceedings, Perth, Australia, 1995

Chong T. Y., Strickland D., Folinsbee J.A, Ron Millions, Fullam M., Grewal I. Recent Gravity improvements at the Porcupine Joint venture. Proceedings-36th Annual Meeting of Canadian Mineral Processors, Paper30, Ottawa, 2004

Darton B.T., Lloyd S., and Antonioli M.A Gravity circuit improvements at the Montana Tunnels Mine, Randol Gold Forum, Proceedings, Perth, Australia, 1995

Ferrara G. A process of centrifugal separation using a rotating tube. 5th International Mineral processing congress, London, IMM, pp. 173-184, 1960

Folinsbee J.A., Chong T.Y., Fullam M. Continuous improvements of porcupine joint venture (PJV) Dome mine's gravity circuit. Proceedings of the International Symposium on the Treatment of Gold Ores, 44th Annual Conference of Metallurgists, Calgary, pp.65-79, COM 2005

Forssberg E., and Nordquist T. Pilot plant trails of new gravity concentration equipment, Technical Note, Minerals and Metallurgical Processing, pp.87-89, 1987

Froehling M., Mohns C., Rajwani R., Fullam M. Reduction of Free Gold Losses in the Cleaner Circuit with the Installation of a Gravity Circuit at the Kemess Mine. Proceedings-38th Annual Meeting of Canadian Mineral Processors, Ottawa, Paper 14, pp211-229, 2007

Gaudin A.M. Principles of Mineral Dressing, McGraw-Hill, NY, 1939

Grewal I. and Fullam M. Gravity circuit optimization via mathematical modeling by particle size classes, April 2004 (www. knelsongravitysolution. com)

Gy P.M. Sampling of particulate materials, Chapter 4, Sampling processes, Elsevier publishing, New York, 1979

Harris D. The Knelson concentrator – Applications in Australia, in Proceedings Gold-mining, Metallurgy and Geology Conference, AIMM, Melbourne, pp.101-106, 1984

Holtham P.N. Particle Transport in Gravity Concentrators and the Bagnold Effect. Minerals Engineering Vol.5 (2), pp.205-221, 1992

Huang L. Upgrading of Gold Gravity Concentrates A study of the Knelson Concentrator. Ph.D Thesis, McGill University, 1996

Huang L and Koppalkar S. Evolution and optimization of the Gravity Recoverable Gold Test, Proceedings-38th Annual Meeting of the Canadian Mineral Processors, Ottawa, Paper 19, pp317-330, 2007

Hart S.D., and Hill G. Gravity separation development at Boddington Gold Mine, Randol Gold Forum Proceedings, Perth, Australia, pp. 53-59, March 1995

Honaker R.Q., Wang D., and Richard Voyles. Evaluation of Full-Scale C40 Concentrator for fine coal cleaning. Coal Preparation, Lexington 1996a

Honaker R. Q., Wang D., Ho K. Application of the Falcon concentrator for fine coal cleaning. Minerals Engineering Vol, 9 No.11, pp 1143-1156, 1996b

Hsu H.W. Separations by centrifugal phenomena. Brisbane, Australia, Wily, 1981

Kelly E G Spottiswood D.J. Introduction to Mineral Processing, John Wiley & Sons, pp.68-69, 1982

Knelson B and Edwards R. Development and economic application of Knelson concentrators in low grade alluvial gold deposits, Annual conference of the AusIMM, Rotorua, New Zealand, 1990

Knelson B. The Knelson Concentrator, Metamorphosis from crude beginning to sophisticated worldwide acceptance. Minerals Engineering Vol, 5 Nos. 10-12, pp.1091-1097, 1992

Knelson B and Jones R. A new generation of Knelson Concentrators. A totally secure system goes on line. Minerals Engineering Vol. 7, Nos.2/3, pp.201-207, 1994

Koppalkar S. and Laplante A.R. Effect of Operating Variables on Knelson concentrators: A Pilot-scale Study. Proceedings-38th Annual Meeting of Canadian Mineral Processors, Ottawa, Paper 16, pp 247-257, 2007

Laplante A.R. Mineralogy and metallurgical performance of various gold copper ores of the Chibougamau area, Quebec. in R.E.Salter, D.M. Wysoluzil and G.W. McDonald (Editors), proceedings of the international symposium on Gold Metallurgy, Pergamon Press, New York, pp. 141-156 1987

Laplante A.R., Liu L., and Cauchon A. Gold gravity recovery at the Mill of Les Mines Camchib Inc., Chibougamau, Quebec. International symposium of gold recovery, Salt Lake City, February, 1990

Laplante A. R., and Shu Y. The Use of a Laboratory Centrifugal Separator to study gravity recovery in Industrial Circuits. Proceedings-24th Annual Meeting of the Canadian Mineral Processors, Paper12, Ottawa, 1992

Laplante A.R. A methodology for the laboratory (7.5 cm) Knelson concentrator, McGill University professional development seminar on Gold Recovery by Gravity, 1993

Laplante A.R., Putz A., and Huang L. Sampling and Sample processing for Gravity circuits, McGill University professional development seminar on Gold Recovery by Gravity, 1993

Laplante A.R., Putz, A., Huang, L, and Vincent, F. Practical Considerations in the Operations of Gold Gravity Circuits. Proceedings-26th Annual Mineral Processors Conference, Ottawa, Paper 23, 1994

Laplante A.R., Huang L., Noaparast M., Nickoletopoulos N. A philosopher's stone : turning tungsten and lead into gold- The use of synthetic ores to study gold gravity separation.Proceedings-27th Annual meeting of Canadian Mineral Processors, Ottawa, Paper 28, pp.379-394, 1995

Laplante A.R., Woodcock, F and Noaparast, M. Predicting Gold Recovery by Gravity. Minerals and Metallurgical Processing, Vol.12, No, 2, pp.74-79, 1995a

Laplante A.R., Shu, Y., and Marois, J. Experimental Characterization of a Laboratory Centrifugal Separator, Canadian Metallurgical Quarterly, Vol.35, No.1, pp.23-29, 1996

Laplante A.R., Huang L., Harris G.B. Defining overload conditions for the 7.6 cm Knelson Concentrator, using synthetic feeds. IMM. (C), London, Vol.105, C75-150, 1996a

Laplante A.R., Vincent F., Luinstra W.F. A Laboratory procedure to determine the amount of gravity recoverable gold – A case study at Hemlo Gold Mines. Proceedings-28th Annual meeting of Canadian Mineral Processors, Ottawa, Paper 6, pp.69-82, 1996b

Laplante A.R., Zhang B., Huang L., Ling J., Cousin P., and Racine L. Difficult gold gravity separations, Proceedings-29th Annual Meeting of Canadian Mineral Processors, Ottawa, Paper 31, pp.421-434, 1997

Laplante A.R., Nickoletopoulos N. Validation of a Falcon Model with a Synthetic Ore. Canadian Metallurgical Quarterly, Vol.36, No. 1, pp.7-13, 1997

Laplante A.R. Testing Requirement and Insight for Gold Gravity Circuit Design, Randol Gold & Silver Forum, Vancouver, pp.73-83, 2000

Laplante A.R., Woodcock F, Huang L. Laboratory procedure to characterize gravity-recoverable gold. Society for Mining, Metallurgy and Exploration, Inc. Vol 308, Transactions 2000

Laplante A.R. Personal communication, 2001

Laplante A.R. and Xiao Z. The Gold Gravity Recovery Effort- A New Concept in the design and optimization of Recovery Circuits. Proceedings-33rd Annual Meeting of Canadian Mineral Processors, Paper 26, pp.371-387, 2001

Laplante A.R. Introduction to gold recovery by gravity, CANMET Gold Recovery Course, 2002

Laplante A.R., Huang L., Harris B.G. The Upgrading of Primary Gold Concentrates. Proceedings of the International Symposium on Gold Recovery, CIM special volume 51, pp.17-25, 2002

Laplante A.R., Dunne R.C. The Gravity recoverable gold test and flash flotation. Proceedings-34th Annual Meeting of the Canadian Mineral Processors, Ottawa, 2002

Laplante A.R., Staunton W.P. Gravity recoverable gold- An Overview of Recent Developments. Proceedings of the International Symposium on the Treatment of Gold Ores, 44th Annual Conference of Metallurgists, Calgary, pp.49-63, COM 2005

Laplante A.R and Clarke J. A simple gravity-recoverable gold test. Proceedings-37th Annual Meeting of the Canadian Mineral Processors, Ottawa, 2006

Laplante A.R. Marvel Loch site visit report 2005, personal communication

Ling J. Variable Speed Knelson Concentrator. Ph.D. Thesis, McGill University, pp.244, 1998

Luttrell G.H., Honaker R.Q., and Phillips D.I. Enhanced gravity separators: New alternatives for Fine Coal Cleaning. 12th International Coal Preparation Conference, Lexington, Kentucky, pp. 281-292, 1995

Malvik T., Sandvik K.L., and Rein A. Scandinavian Experiences with the Kelsey Centrifugal Jig. Innovation in Physical Separation Technologies Falmouth, IMM. pp113-122, 1997

Majumder A. K. Modelling of Flowing film Concentrators. Ph.D. Thesis, JKMRC, University of Queensland, pp.6-8, 2002

McLeavy M., Klein B., and Grewal I. Knelson continuous variable discharge concentrator: Analysis of operating variables, International heavy minerals conference, Fremantle, WA, 18-19 June 2001

Meza S., Hartmann W., and Escobar C.A. Recovery of placer gold using the Knelson Concentrator. Proceedings-Innovations in Mineral Processing, Sudbury, Canada, pp.339-347, 1994

Nesset E.J., Mackey P.J., Kim J.Y., Laplante A.R., Prisco G.D. Low grade Cu-Au Deposits: Predicting the relationship between copper and gold performance in flotation and the potential for gravity gold recovery. Proceedings-37th annual meeting of the Canadian Mineral Processors Ottawa Paper 38, pp. 683-699, 2005

Putz A., Laplante, A.R., and Ladouceur, G. Evaluation of a gravity circuit in a Canadian gold operation. Proceedings, Randol Gold Forum, Beaver Creek, pp. 145-149, 1993

Putz A. An investigation of the Gravity recovery of gold, M.Eng. Thesis, McGill University, pp.230, 1994

Poulter S., Fitzmaurice C., and Steward G. The Knelson Concentrator: Application and operation at Rosebery, Proceedings of Fifth Mill Operators' Conference, Roxby Downs, October, pp. 227 -233, 1994

Sargent D and Subasinghe G.K.N. Selecting Optimal Operating Conditions for Knelson Concentrators. Metallurgical Plant Design and Operating Strategies (MetPlant 2006), 18-19 September, Perth, WA, pp.274-289, 2006

Scales M. The big Dome celebrates 80 years, Canadian Mining Journal, pp. 3-23, 1989

Spiller D.E and Rau E.L. Colorado School of Mines Research Institute report, p.5, 1982

Subasinghe G.K.N. Evaluating an alternative to the Gravity Recoverable Gold (GRG) Test. Ninth Mill Operators' Conference, Fremantle, WA, 19-21, pp.235-239, March 2007

Subasinghe G.K.N. Optimizing Knelson Concentrator Performance in Gravity Gold Circuits. XVII International Mineral Processing Congress, Beijing, China, pp.717-723, 2008

Spiller D.E. Gravity separation of gold Then and now. Mining Yearbook, pp.79-82, 1983

Suttill K.R. Merro De Ouro - Brazil's hill of gold, E/MJ, June, pp. 25-28, 1990

Vincent F. A comparison of Knelson concentrator and jig performance for gravity recovery, M. Eng. Thesis, McGill University, pp.131, 1997

Walsh D.E. and Rao P.D. Development of a radiotracer technique to evaluate gold recovery by gravity concentrators, CIM Bulletin, 1986

Wells J. and Patel C. Contemporary practices in gravity recovery installations in the Canadian gold mining industry. Minerals engineering, vol. 4, pp.399-409, 1991

Woodcock F., and Laplante A.R. A laboratory method for determining the amount of Gravity recoverable gold. Proceedings, Randol Gold Forum, Beaver Creek, pp.151-155, 1993

Woodcock F. Use of a Knelson Unit to Quantify Gravity recoverable gold in an ore. M. Eng. Thesis, McGill University, pp.128, 1994

www.Knelsongravitysolutions.com

www.mining-technology.com/contractors/separation/axsia/

Xiao J. Testing a new gold centrifugal concentrator, M. Eng. Thesis, McGill University, pp.131, 1998

Xiao Z., and Laplante A.R. Characterizing and recovering Platinum group minerals- A review. Minerals Engineering, Vol.17, pp.961-979, 2004

Zhang B. Recovering Gold from High Density gangues with Knelson concentrators. M. Eng thesis. McGill University, pp.110, 1998

Appendix 1 Operating conditions of the pilot Knelson KC CD12 test

Table 22: Operating conditions of the pilot tests

S.No.	Test #	Test Type	Pilot Knelson KCCD12 test conditions					
			Feed rate (t/hr)	Screen size (mm)	Fluidiz flow m3/hr (USGPM)	%Solids	G-force	Cycle time (min)
1	1	Short	8.8	2.0	5.7 (25)	34	90	30
2	2	Short	9.7	2.0	2.7 (12)	41	60	30
3	3	Short	9.6	2.0	3.6 (16)	40	60	30
4	4	Short	11.3	2.0	4.1 (18)	44	40	30
5	5	Short	10.8	2.0	4.1 (18)	41	90	30
6	7	Short	13.6	2.0	4.5 (20)	44	60	30
7	10	Short	9.3	2.0	2.7 (12)	39	40	30
8	14	Short	14.1	2.0	2.7 (12)	38	60	30
9	16	Short	6.6	1.0	2.7 (12)	34	60	30
10	17	Short	7.8	3.5	6.4 (28)	33	60	30
11	19	Short	13.3	3.5	4.5 (20)	40	60	30
12	26	Short	13.1	2.0	4.5 (20)	35	60	30
13	11	Long	7.7	2.0	4.5 (20)	32	60	90
14	15	Long	7.7	1.0	4.5 (20)	32	60	90
15	18	Long	8	3.5	4.5 (20)	38	60	90
16	1	Short	13.3	3.5	4.5 (20)	41	60	30
17	2	Short	14.5	1.0	4.5 (20)	44	60	30
18	3	Short	13.9	1.0	4.1 (18)	42	40	30
19	4	Short	13.9	1.0	4.5 (20)	44	90	30
20	6	Short	18.3	3.5	3.2 (14)	49	40	30
21	7	Short	18.9	3.5	2.3 (10)	45	60	30
22	8	Short	17.4	3.5	5.2 (23)	45	90	30
23	9	Short	16.1	3.5	5.2 (23)	46	60	30
24	10	Short	16.2	3.5	4.1 (18)	48	40	30
25	11	Short	16.4	3.5	4.1 (18)	48	60	30
26	13	Short	16.5	3.5	5.2 (23)	50	40	30
27	14	Short	14.7	3.5	4.5 (20)	55	60	30
28	15	Short	15.4	3.5	4.5 (20)	47	60	30
29	16	Short	15.2	3.5	4.5 (20)	55	60	30
30	5	Long	14.3	1.0	4.5 (20)	44	60	90
31	12	Long	17.9	3.5	4.5 (20)	49	60	90

Appendix 2 LKC and pilot Knelson concentrator metallurgical balances: campaign 1

Table 23: Metallurgical balance of laboratory Knelson concentrator (Test 1)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.37	9.68	76	13.65	1728	7.29	2.60	86.35	1738	7.30	2.99	3.85
425	13.38	13.83	204	49.99	2736	11.53	1.00	50.01	2750	11.54	1.99	4.05
300	18.21	18.82	469	51.86	3548	14.95	2.23	48.14	3566	14.97	4.62	12.19
212	20.66	21.35	630	56.61	5072	21.38	1.97	43.39	5093	21.38	4.51	17.03
150	17.68	18.27	921	66.83	3911	16.48	2.07	33.17	3928	16.49	6.20	18.05
106	9.87	10.20	1475	65.92	2376	10.02	3.17	34.08	2386	10.02	9.26	16.35
75	4.29	4.43	2107	56.60	1276	5.38	5.43	43.40	1280	5.37	12.48	11.83
53	1.93	1.99	2786	51.65	884	3.73	5.69	48.35	886	3.72	11.75	7.71
37	0.81	0.84	3116	69.48	387	1.63	2.88	30.52	388	1.63	9.41	2.70
25	0.347	0.36	5363	90.91	302	1.27	0.62	9.09	303	1.27	6.76	1.51
-25	0.224	0.23	9631	33.92	1503	6.34	2.80	66.08	1503	6.31	4.24	4.72
Total	96.77	100	794	56.89	23723	100	2.45	43.11	23820	100	5.67	100

Table 24: Metallurgical balance of pilot Knelson concentrator (Test 1)

Size (µm)	CONCENTRATE Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00060	8.63	2725	93.47	0.28	7.30	0.41	6.53	0.28	7.30	6.24	3.39
425	0.00091	13.14	1881	79.59	0.44	11.54	0.99	20.41	0.44	11.55	4.86	4.18
300	0.00120	17.37	1855	61.98	0.57	14.97	2.39	38.02	0.57	14.97	6.28	7.00
212	0.00136	19.66	2371	60.73	0.82	21.38	2.56	39.27	0.82	21.38	6.50	10.33
150	0.00105	15.15	3740	60.04	0.63	16.49	4.15	39.96	0.63	16.49	10.36	12.70
106	0.00077	11.06	6184	66.98	0.38	10.02	6.10	33.02	0.38	10.02	18.44	13.74
75	0.00036	5.25	10146	71.79	0.21	5.37	7.06	28.21	0.21	5.37	24.99	9.99
53	0.00030	4.36	32106	91.84	0.14	3.72	6.07	8.16	0.14	3.72	74.16	20.52
37	0.00012	1.73	50303	93.69	0.06	1.63	6.54	6.31	0.06	1.63	103.36	12.52
25	0.00019	2.75	10236	86.75	0.05	1.27	6.14	13.25	0.05	1.27	46.16	4.37
-25	0.00006	0.89	5017	47.14	0.24	6.31	1.44	52.86	0.24	6.30	2.72	1.27
Total	0.00693	100	5653	76.06	3.82	100	3.22	23.94	3.83	100	13.45	100

Table 25: Metallurgical balance of laboratory Knelson concentrator (Test 2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.30	11.48	45	7.33	2325	8.78	2.50	92.67	2335	8.79	2.69	3.32
425	13.49	15.03	414	27.78	3568	13.48	4.07	72.22	3582	13.49	5.61	10.64
300	17.10	19.05	387	24.07	4501	17.00	4.63	75.93	4518	17.01	6.08	14.54
212	18.86	21.01	680	58.34	5977	22.58	1.53	41.66	5995	22.57	3.67	11.64
150	15.78	17.58	1454	62.73	4215	15.92	3.23	37.27	4231	15.93	8.64	19.35
106	8.45	9.41	2138	67.84	2379	8.99	3.60	32.16	2387	8.99	11.15	14.10
75	3.48	3.88	3659	62.72	1224	4.62	6.19	37.28	1227	4.62	16.54	10.75
53	1.48	1.65	6650	66.82	779	2.94	6.27	33.18	781	2.94	18.87	7.80
37	0.48	0.53	8774	88.60	324	1.23	1.65	11.40	325	1.22	14.49	2.49
25	0.204	0.23	13033	94.78	246	0.93	0.59	5.22	246	0.93	11.37	1.48
-25	0.140	0.16	30208	57.15	933	3.52	3.39	42.85	933	3.51	7.91	3.91
Total	89.76	100	1115	52.98	26470	100	3.36	47.02	26560	100	7.11	100

Table 26: Metallurgical balance of pilot Knelson concentrator (Test 2)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00029	8.69	7431	96.73	0.37	8.79	0.20	3.27	0.37	8.79	6.02	4.44
425	0.00042	12.75	4001	65.83	0.57	13.49	1.56	34.17	0.57	13.48	4.56	5.16
300	0.00055	16.55	8037	80.92	0.71	17.01	1.46	19.08	0.71	17.01	7.66	10.94
212	0.00063	18.82	5589	63.35	0.95	22.57	2.14	36.65	0.95	22.57	5.83	11.05
150	0.00052	15.50	10418	59.74	0.67	15.93	5.42	40.26	0.67	15.93	13.46	17.99
106	0.00037	11.23	11913	60.96	0.38	8.99	7.57	39.04	0.38	8.99	19.36	14.61
75	0.00019	5.78	14984	58.89	0.19	4.62	10.38	41.11	0.19	4.62	25.22	9.78
53	0.00018	5.45	23701	73.46	0.12	2.94	12.61	26.54	0.12	2.94	47.44	11.71
37	0.00007	2.23	33115	78.88	0.05	1.22	12.84	21.12	0.05	1.22	60.70	6.24
25	0.00003	0.81	56852	78.54	0.04	0.93	10.78	21.46	0.04	0.93	50.19	3.91
-25	0.00007	2.19	19507	68.06	0.15	3.51	4.52	31.94	0.15	3.51	14.15	4.17
Total	0.00333	100	10275	68.39	4.19	100	3.77	31.61	4.20	100	11.91	100

Table 27: Metallurgical balance of laboratory Knelson concentrator (Test 3)

Size	CONCENTRATE				TAILS				FEED (Pilot Knleson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.51	11.19	121	68.18	1268	5.31	0.47	31.82	1279	5.34	1.46	1.40
425	14.45	15.38	214	66.60	1938	8.12	0.80	33.40	1952	8.15	2.38	3.50
300	18.19	19.36	535	45.22	2762	11.57	4.27	54.78	2780	11.60	7.74	16.21
212	19.59	20.85	649	73.07	4538	19.01	1.03	26.93	4557	19.02	3.82	13.11
150	16.16	17.20	802	50.82	4091	17.14	3.07	49.18	4107	17.14	6.21	19.22
106	8.78	9.35	1321	62.73	2683	11.24	2.57	37.27	2692	11.24	6.87	13.93
75	3.66	3.90	2156	56.08	1545	6.47	4.00	43.92	1549	6.46	9.09	10.60
53	1.57	1.67	3907	52.08	1105	4.63	5.11	47.92	1107	4.62	10.64	8.87
37	0.66	0.70	5705	73.24	551	2.31	2.49	26.76	551	2.30	9.30	3.86
25	0.240	0.26	11153	70.27	456	1.91	2.49	29.73	456	1.91	8.36	2.87
-25	0.134	0.14	25850	40.49	2929	12.27	1.73	59.51	2929	12.23	2.91	6.43
Total	93.94	100	801	56.71	23866	100	2.41	43.29	23960	100	5.54	100

Table 28: Metallurgical balance of pilot Knelson concentrator (Test 3)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00029	8.39	4868	86.59	0.22	5.34	0.99	13.41	0.22	5.34	7.39	3.01
425	0.00043	12.57	4397	78.19	0.34	8.15	1.58	21.81	0.34	8.15	7.25	4.50
300	0.00057	16.41	4245	58.96	0.48	11.60	3.50	41.04	0.48	11.61	8.52	7.53
212	0.00064	18.62	3422	50.13	0.79	19.02	2.79	49.87	0.79	19.02	5.59	8.10
150	0.00054	15.65	10946	72.62	0.71	17.14	3.16	27.38	0.71	17.14	11.52	15.04
106	0.00041	11.83	9353	65.69	0.46	11.24	4.31	34.31	0.46	11.24	12.54	10.73
75	0.00021	6.09	63798	90.81	0.27	6.46	5.10	9.19	0.27	6.46	55.42	27.28
53	0.00019	5.46	18128	76.41	0.19	4.62	5.54	23.59	0.19	4.62	23.47	8.26
37	0.00007	1.94	16938	63.74	0.10	2.30	6.81	36.26	0.10	2.30	18.77	3.29
25	0.00003	0.79	29868	63.96	0.08	1.91	5.87	36.04	0.08	1.90	16.29	2.36
-25	0.00008	2.23	62033	88.92	0.51	12.23	1.18	11.08	0.51	12.22	10.64	9.90
Total	0.003460	100	11941	76.09	4.13	100.00	3.14	23.91	4.14	100	13.13	100

Table 29: Metallurgical balance of laboratory Knelson concentrator (Test 4)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.23	8.63	18	3.66	1936	7.21	2.00	96.34	1944	7.22	2.07	2.49
425	13.08	13.72	1902	90.63	2968	11.06	0.87	9.37	2981	11.06	9.21	16.97
300	17.79	18.65	417	52.07	3867	14.41	1.77	47.93	3885	14.42	3.67	8.82
212	20.15	21.13	502	48.86	5476	20.40	1.93	51.14	5496	20.40	3.77	12.80
150	18.06	18.94	712	59.14	4298	16.01	2.07	40.86	4316	16.02	5.04	13.44
106	10.45	10.96	1270	63.97	2607	9.71	2.87	36.03	2618	9.72	7.92	12.83
75	4.50	4.72	2105	59.44	1436	5.35	4.50	40.56	1440	5.35	11.06	9.85
53	1.96	2.06	4086	65.45	1012	3.77	4.18	34.55	1013	3.76	12.07	7.57
37	0.76	0.80	8013	87.83	471	1.76	1.79	12.17	472	1.75	14.71	4.29
25	0.252	0.26	20233	92.20	373	1.39	1.16	7.80	374	1.39	14.80	3.42
-25	0.133	0.14	51283	55.90	2401	8.94	2.23	44.10	2401	8.91	5.06	7.52
Total	95.37	100	1092	64.41	26845	100	2.14	35.59	26940	100	6.00	100

Table 30: Metallurgical balance of pilot Knelson concentrator (Test 4)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00034	9.92	6237	98.74	0.35	7.22	0.08	1.26	0.35	7.22	6.01	3.66
425	0.00046	13.62	3086	23.98	0.54	11.06	8.35	76.02	0.54	11.07	10.97	10.24
300	0.00057	16.73	4786	66.80	0.71	14.42	1.91	33.20	0.71	14.42	5.75	7.00
212	0.00064	18.84	3626	55.77	1.00	20.40	1.84	44.23	1.00	20.40	4.16	7.16
150	0.00053	15.61	5903	57.23	0.79	16.02	2.98	42.77	0.79	16.02	6.96	9.41
106	0.00039	11.52	20122	76.52	0.48	9.72	5.07	23.48	0.48	9.72	21.58	17.69
75	0.00018	5.23	19131	66.34	0.26	5.35	6.58	33.66	0.26	5.35	19.52	8.81
53	0.00014	3.99	72399	87.05	0.18	3.76	7.90	12.95	0.18	3.76	61.00	19.36
37	0.00005	1.58	72841	77.84	0.09	1.75	12.92	22.16	0.09	1.75	58.25	8.61
25	0.00003	0.74	57185	60.63	0.07	1.39	13.64	39.37	0.07	1.39	34.64	4.05
-25	0.00008	2.24	14427	47.00	0.44	8.91	2.83	53.00	0.44	8.91	5.34	4.01
Total	0.00340	100	11538	67.40	4.91	100	3.87	32.60	4.91	100	11.85	100

Table 31: Metallurgical balance of laboratory Knelson concentrator (Test 5)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson Tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.99	8.55	18	5.80	964	6.96	2.43	94.20	972	6.97	2.56	2.31
425	12.69	13.58	212	46.63	1487	10.74	2.07	53.37	1500	10.76	3.84	5.35
300	17.23	18.44	354	64.93	1977	14.28	1.67	35.07	1994	14.30	4.71	8.73
212	19.40	20.77	439	46.29	2847	20.56	3.47	53.71	2866	20.56	6.41	17.08
150	17.30	18.52	689	52.84	2232	16.12	4.77	47.16	2250	16.14	10.03	20.97
106	10.70	11.45	934	61.98	1373	9.92	4.47	38.02	1384	9.93	11.66	14.99
75	4.82	5.16	1411	56.87	781	5.64	6.60	43.13	786	5.64	15.21	11.12
53	2.10	2.25	1856	47.52	558	4.03	7.72	52.48	560	4.02	14.65	7.62
37	0.78	0.83	2734	52.45	263	1.90	7.34	47.55	264	1.89	15.39	3.78
25	0.259	0.28	3644	38.43	207	1.50	7.28	61.57	208	1.49	11.81	2.28
-25	0.158	0.17	11125	28.41	1156	8.35	3.83	71.59	1156	8.29	5.35	5.75
Total	93.43	100	588	51.02	13846	100	3.81	48.98	13939	100	7.72	100

Table 32: Metallurgical balance of pilot Knelson concentrator (Test 5)

Size (µm)	CONCENTRATE Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00029	7.32	4726	96.59	0.33	6.97	0.15	3.41	0.33	6.97	4.36	2.89
425	0.00046	11.40	3467	63.55	0.51	10.76	1.79	36.45	0.51	10.76	4.91	5.02
300	0.00063	15.63	3427	50.98	0.67	14.30	3.06	49.02	0.67	14.31	6.24	8.47
212	0.00075	18.80	2506	39.60	0.97	20.56	2.97	60.40	0.97	20.56	4.91	9.59
150	0.00062	15.57	7911	55.02	0.76	16.14	5.30	44.98	0.76	16.14	11.77	18.05
106	0.00048	11.87	11876	62.55	0.47	9.93	7.22	37.45	0.47	9.93	19.27	18.18
75	0.00025	6.24	14811	61.67	0.27	5.64	8.65	38.33	0.27	5.64	22.54	12.08
53	0.00024	5.93	20666	78.83	0.19	4.02	6.96	21.17	0.19	4.02	32.84	12.54
37	0.00010	2.43	29444	79.88	0.09	1.89	8.07	20.12	0.09	1.89	40.09	7.21
25	0.00014	3.46	12526	84.48	0.07	1.49	4.54	15.52	0.07	1.49	29.18	4.13
-25	0.00005	1.34	5967	35.03	0.39	8.29	1.52	64.97	0.39	8.29	2.34	1.84
Total	0.00400	100	7768	62.63	4.71	100	3.94	37.37	4.71	100	10.53	100

Table 33: Metallurgical balance of laboratory Knelson concentrator (Test 7)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.30	7.76	39	16.84	1264	6.90	1.10	83.16	1271	6.90	1.32	1.58
425	12.69	13.49	276	55.08	1995	10.88	1.43	44.92	2007	10.90	3.17	6.00
300	18.06	19.20	400	62.60	2643	14.42	1.63	37.40	2661	14.44	4.34	10.88
212	20.16	21.44	427	57.19	3722	20.31	1.73	42.81	3742	20.31	4.03	14.20
150	17.71	18.83	540	57.00	2813	15.35	2.57	43.00	2830	15.36	5.93	15.83
106	10.40	11.06	951	63.29	1639	8.94	3.50	36.71	1650	8.96	9.47	14.73
75	4.63	4.92	1556	61.67	898	4.90	4.99	38.33	903	4.90	12.94	11.01
53	2.01	2.14	3131	61.86	628	3.42	6.18	38.14	630	3.42	16.16	9.59
37	0.65	0.69	4710	61.82	326	1.78	5.80	38.18	327	1.78	15.15	4.67
25	0.275	0.29	8023	62.86	279	1.52	4.69	37.14	279	1.51	12.60	3.31
-25	0.160	0.17	11520	21.20	2122	11.58	3.23	78.80	2122	11.52	4.10	8.21
Total	94.05	100	635	56.28	18328	100	2.53	43.72	18422	100	5.76	100

Table 34: Metallurgical balance of pilot Knelson concentrator (Test 7)

Size (µm)	CONCENTRATE Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00033	9.62	2725	90.85	0.41	6.90	0.22	9.15	0.41	6.90	2.42	2.63
425	0.00047	13.75	1881	44.03	0.65	10.90	1.75	55.97	0.65	10.90	3.12	5.35
300	0.00059	17.14	1855	31.94	0.86	14.44	2.71	68.06	0.86	14.45	3.99	9.07
212	0.00066	19.17	2371	36.00	1.21	20.31	2.30	64.00	1.21	20.31	3.60	11.50
150	0.00054	15.67	3740	39.50	0.91	15.36	3.38	60.50	0.91	15.36	5.59	13.52
106	0.00039	11.25	6184	42.85	0.53	8.96	6.00	57.15	0.53	8.96	10.49	14.79
75	0.00018	5.34	10146	44.48	0.29	4.90	7.98	55.52	0.29	4.90	14.36	11.09
53	0.00014	4.18	32106	69.44	0.20	3.42	10.00	30.56	0.20	3.42	32.68	17.59
37	0.00005	1.53	50303	72.78	0.11	1.78	9.37	27.22	0.11	1.77	34.39	9.61
25	0.00002	0.66	10236	24.61	0.09	1.51	7.92	75.39	0.09	1.51	10.51	2.50
-25	0.00006	1.69	5016.6	32.88	0.68	11.52	0.87	67.12	0.68	11.51	1.30	2.35
Total	0.003438	100	5379	48.99	5.94	100	3.24	51.01	5.95	100	6.35	100

Table 35: Metallurgical balance of laboratory Knelson concentrator (Test 10)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	7.04	7.62	20	6.77	903	6.90	2.10	93.23	910	6.90	2.24	3.31
425	12.52	13.55	132	45.06	1439	11.00	1.40	54.94	1452	11.01	2.53	5.97
300	17.69	19.15	166	51.01	1927	14.73	1.47	48.99	1945	14.76	2.97	9.39
212	19.84	21.47	260	55.77	2790	21.32	1.47	44.23	2810	21.32	3.29	15.06
150	17.92	19.39	337	60.83	2159	16.50	1.80	39.17	2177	16.52	4.56	16.15
106	10.14	10.97	507	57.74	1268	9.69	2.97	42.26	1278	9.70	6.97	14.49
75	4.27	4.62	865	53.66	667	5.09	4.78	46.34	671	5.09	10.25	11.20
53	1.80	1.95	1603	52.51	460	3.52	5.67	47.49	462	3.51	11.89	8.95
37	0.69	0.74	2322	55.06	227	1.74	5.71	44.94	228	1.73	12.68	4.71
25	0.263	0.28	4280	53.61	199	1.52	4.90	46.39	199	1.51	10.54	3.41
-25	0.228	0.25	5252	26.52	1049	8.01	3.17	73.48	1049	7.96	4.31	7.36
Total	92.40	100	342	51.38	13088	100	2.28	48.62	13180	100	4.66	100

Table 36: Metallurgical balance of pilot Knelson concentrator (Test 10)

Size (µm)	CONCENTRATE Weight (Tons)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (Tons)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED Weight (Tons)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	0.00031	9.04	2151	94.09	0.28	6.90	0.15	5.91	0.28	6.90	2.56	2.76
425	0.00046	13.42	2023	64.93	0.44	11.01	1.14	35.07	0.44	11.02	3.24	5.58
300	0.00057	16.59	1749	52.62	0.59	14.76	1.51	47.38	0.59	14.76	3.19	7.36
212	0.00063	18.38	2789	52.80	0.85	21.32	1.84	47.20	0.85	21.32	3.89	12.95
150	0.00052	15.20	4304	54.97	0.66	16.52	2.77	45.03	0.66	16.52	6.15	15.87
106	0.00040	11.82	5060	56.73	0.39	9.70	4.02	43.27	0.39	9.70	9.28	14.07
75	0.00021	6.10	8724	61.89	0.20	5.09	5.50	38.11	0.20	5.09	14.42	11.47
53	0.00017	4.94	16062	75.60	0.14	3.51	6.25	24.40	0.14	3.51	25.56	14.01
37	0.00006	1.82	26521	77.32	0.07	1.73	6.98	22.68	0.07	1.73	30.74	8.31
25	0.00002	0.73	19968	59.44	0.06	1.51	5.65	40.56	0.06	1.51	13.93	3.28
-25	0.00007	1.95	11187	67.20	0.32	7.96	1.14	32.80	0.32	7.95	3.48	4.33
Total	0.00341	100	4694	62.62	3.99	100	2.39	37.38	4.00	100	6.40	100

Table 37: Metallurgical balance of laboratory Knelson concentrator (Test 14)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	8.57	9.36	10	4.82	1194	7.53	1.40	95.18	1203	7.54	1.46	2.78
425	13.39	14.62	133	37.61	1852	11.67	1.60	62.39	1865	11.69	2.55	7.52
300	17.89	19.53	193	45.97	2436	15.36	1.67	54.03	2454	15.38	3.06	11.90
212	19.80	21.61	244	47.48	3405	21.46	1.57	52.52	3424	21.46	2.97	16.09
150	16.96	18.51	351	60.50	2536	15.99	1.53	39.50	2553	16.00	3.85	15.59
106	9.26	10.11	544	54.07	1426	8.99	3.00	45.93	1435	8.99	6.49	14.75
75	3.65	3.98	857	47.22	732	4.61	4.78	52.78	736	4.61	9.01	10.50
53	1.42	1.55	1726	51.73	485	3.06	4.72	48.27	486	3.05	9.75	7.51
37	0.45	0.50	3127	56.94	239	1.51	4.50	43.06	240	1.50	10.42	3.96
25	0.139	0.15	6829	50.12	206	1.30	4.60	49.88	206	1.29	9.21	3.01
-25	0.070	0.08	15783	27.34	1355	8.54	2.17	72.66	1355	8.49	2.98	6.40
Total	91.60	100	330	47.83	15865	100	2.08	52.17	15957	100	3.96	100

Table 38: Metallurgical balance of pilot Knelson concentrator (Test 14)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0006	10.10	2146	97.59	0.46	7.54	0.07	2.41	0.46	7.54	2.92	4.48
425	0.0009	14.63	1001	56.48	0.71	11.69	0.96	43.52	0.71	11.69	2.20	5.24
300	0.0011	18.01	1378	53.21	0.94	15.38	1.41	46.79	0.94	15.38	3.01	9.42
212	0.0012	19.96	1948	56.07	1.31	21.46	1.41	43.93	1.31	21.46	3.20	14.01
150	0.0009	15.55	3453	58.81	0.98	16.00	2.33	41.19	0.98	16.00	5.66	18.44
106	0.0006	10.37	4200	57.78	0.55	8.99	3.51	42.22	0.55	8.99	8.30	15.22
75	0.0003	4.39	6316	58.38	0.28	4.61	4.25	41.62	0.28	4.61	10.21	9.60
53	0.0002	3.21	11846	71.05	0.19	3.05	5.04	28.95	0.19	3.05	17.40	10.81
37	0.0001	1.25	18733	72.24	0.09	1.50	5.93	27.76	0.09	1.50	21.35	6.54
25	0.0000	0.69	13772	61.41	0.08	1.29	4.62	38.59	0.08	1.29	11.95	3.15
-25	0.0001	1.83	4569	54.49	0.52	8.49	0.82	45.51	0.52	8.48	1.79	3.10
Total	0.0060	100	3044	61.47	6.10	100	1.89	38.53	6.10	100	4.91	100

Table 39: Metallurgical balance of laboratory Knelson concentrator (Test 16)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.41	10.19	24	5.18	896	6.66	4.70	94.82	906	6.68	4.91	9.57
425	13.58	14.71	49	25.84	1436	10.67	1.33	74.16	1450	10.70	1.78	5.56
300	18.20	19.71	64	36.56	1956	14.53	1.03	63.44	1974	14.56	1.61	6.86
212	20.09	21.76	149	27.74	2860	21.24	2.73	72.26	2880	21.25	3.76	23.30
150	16.70	18.08	182	38.82	2244	16.67	2.13	61.18	2261	16.68	3.46	16.85
106	8.90	9.64	242	42.58	1302	9.67	2.23	57.42	1311	9.67	3.86	10.91
75	3.27	3.54	453	37.60	658	4.89	3.73	62.40	662	4.88	5.95	8.48
53	1.29	1.40	827	38.62	430	3.20	3.94	61.38	432	3.18	6.40	5.95
37	0.51	0.56	1284	33.95	213	1.58	6.03	66.05	214	1.58	9.11	4.20
25	0.192	0.21	2344	42.79	185	1.38	3.25	57.21	185	1.37	5.67	2.27
-25	0.197	0.21	2778	19.44	1281	9.52	1.77	80.56	1282	9.45	2.19	6.05
Total	92.34	100	157	31.15	13464	100	2.37	68.85	13556	100	3.42	100

Table 40: Metallurgical balance of pilot Knelson concentrator (Test 16)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0003	7.78	1434	88.62	0.19	6.68	0.25	11.38	0.19	6.68	2.23	2.58
425	0.0004	11.93	2251	86.62	0.31	10.70	0.46	13.38	0.31	10.70	3.43	6.35
300	0.0005	16.03	872	65.87	0.42	14.56	0.59	34.13	0.42	14.56	1.73	4.35
212	0.0007	18.98	1218	55.33	0.61	21.25	1.04	44.67	0.62	21.25	2.33	8.56
150	0.0006	16.25	4977	81.06	0.48	16.68	1.34	18.94	0.48	16.68	7.09	20.43
106	0.0004	12.10	5558	83.37	0.28	9.67	1.64	16.63	0.28	9.67	9.88	16.52
75	0.0002	5.98	8201	84.19	0.14	4.88	2.24	15.81	0.14	4.88	14.14	11.93
53	0.0002	5.35	12849	91.19	0.09	3.18	2.47	8.81	0.09	3.19	28.01	15.43
37	0.0001	2.12	14759	88.38	0.05	1.58	3.09	11.62	0.05	1.58	26.56	7.25
25	0.0000	0.87	13377	80.65	0.04	1.37	2.43	19.35	0.04	1.37	12.53	2.96
-25	0.0001	2.61	5523	80.93	0.27	9.45	0.43	19.07	0.27	9.45	2.24	3.65
Total	0.0034	100	3983	81.58	2.89	100	1.07	18.42	2.90	100	5.78	100

Table 41: Metallurgical balance of laboratory Knelson concentrator (Test 17)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.81	8.63	270	71.39	768	6.94	1.10	28.61	775	6.95	3.81	5.05
425	12.63	13.95	213	68.05	1225	11.07	1.03	31.95	1237	11.09	3.20	6.77
300	17.22	19.03	187	58.06	1625	14.68	1.43	41.94	1642	14.72	3.38	9.49
212	19.95	22.04	191	43.24	2351	21.25	2.13	56.76	2371	21.25	3.73	15.11
150	17.19	18.99	252	48.39	1848	16.69	2.50	51.61	1865	16.71	4.80	15.30
106	9.35	10.33	393	27.53	1075	9.72	9.00	72.47	1085	9.72	12.31	22.84
75	3.60	3.98	589	46.20	557	5.04	4.43	53.80	561	5.03	8.19	7.85
53	1.53	1.69	1073	48.84	369	3.34	4.66	51.16	371	3.32	9.07	5.75
37	0.69	0.77	1631	55.96	177	1.60	5.03	44.04	178	1.59	11.37	3.46
25	0.286	0.32	2493	45.94	152	1.38	5.51	54.06	153	1.37	10.17	2.66
-25	0.245	0.27	3291	24.10	919	8.30	2.77	75.90	919	8.24	3.64	5.73
Total	90.51	100	290	44.92	11066	100	2.91	55.08	11157	100	5.24	100

Table 42: Metallurgical balance of pilot Knelson concentrator (Test 17)

Size (µm)	CONCENTRATE Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0004	6.30	1371	50.45	0.21	6.95	2.72	49.55	0.21	6.95	5.47	7.16
425	0.0006	9.44	1004	46.63	0.33	11.09	2.18	53.37	0.33	11.09	4.07	8.50
300	0.0008	12.72	434	29.83	0.44	14.72	1.96	70.17	0.44	14.71	2.79	7.73
212	0.0011	16.27	715	43.06	0.63	21.25	1.61	56.94	0.64	21.24	2.82	11.30
150	0.0011	15.94	873	44.37	0.50	16.71	2.32	55.63	0.50	16.71	4.17	13.11
106	0.0009	14.10	1442	57.85	0.29	9.72	3.39	42.15	0.29	9.73	8.02	14.69
75	0.0005	7.73	1329	54.59	0.15	5.03	3.78	45.41	0.15	5.03	8.30	7.87
53	0.0005	7.98	3837	82.24	0.10	3.32	4.43	17.76	0.10	3.33	24.79	15.57
37	0.0002	3.47	3889	74.77	0.05	1.59	6.36	25.23	0.05	1.60	25.10	7.55
25	0.0001	2.23	2777	68.31	0.04	1.37	4.67	31.69	0.04	1.37	14.69	3.79
-25	0.0003	3.82	856	50.17	0.25	8.24	0.88	49.83	0.25	8.23	1.76	2.73
Total	0.0066	100	1334	55.77	2.98	100	2.35	44.23	2.99	100	5.31	100

Table 43: Metallurgical balance of laboratory Knelson concentrator (Test 19)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.42	8.82	259	61.92	1006	7.05	1.33	38.08	1014	7.06	3.47	4.66
425	13.18	13.81	136	46.17	1605	11.25	1.30	53.83	1618	11.26	2.40	5.13
300	18.56	19.44	264	55.78	2155	15.10	1.80	44.22	2173	15.13	4.04	11.61
212	20.90	21.89	328	44.64	3073	21.54	2.77	55.36	3094	21.54	4.96	20.32
150	17.74	18.58	349	55.48	2327	16.30	2.13	44.52	2344	16.32	4.75	14.75
106	10.26	10.75	632	62.52	1296	9.08	3.00	37.48	1306	9.09	7.94	13.72
75	4.10	4.30	1028	62.64	658	4.61	3.82	37.36	662	4.61	10.16	8.90
53	1.48	1.55	2286	58.55	443	3.11	5.40	41.45	445	3.10	12.99	7.65
37	0.50	0.52	4100	65.93	211	1.48	5.01	34.07	212	1.48	14.67	4.12
25	0.167	0.17	7656	57.05	189	1.32	5.09	42.95	189	1.32	11.84	2.96
-25	0.152	0.16	9817	31.99	1307	9.16	2.43	68.01	1308	9.10	3.58	6.19
Total	95.46	100	428	53.99	14271	100	2.44	46.01	14366	100	5.26	100

Table 44: Metallurgical balance of pilot Knelson concentrator (Test 19)

Size (µm)	CONCENTRATE Weight (Tons)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (Tons)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED Weight (Tons)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	0.0004	6.23	838	30.85	0.36	7.06	2.15	69.15	0.36	7.06	3.10	4.63
425	0.0006	9.47	726	41.71	0.58	11.26	1.11	58.29	0.58	11.26	1.90	4.51
300	0.0009	12.97	1047	34.08	0.78	15.13	2.25	65.92	0.78	15.13	3.41	10.91
212	0.0011	16.44	1121	33.36	1.10	21.54	2.22	66.64	1.11	21.53	3.32	15.12
150	0.0010	15.66	1542	42.10	0.84	16.32	2.64	57.90	0.84	16.32	4.55	15.69
106	0.0009	13.99	834	25.09	0.47	9.09	4.96	74.91	0.47	9.10	6.61	12.72
75	0.0005	7.93	2500	46.71	0.24	4.61	6.37	53.29	0.24	4.61	11.92	11.62
53	0.0005	8.15	2867	56.25	0.16	3.10	7.61	43.75	0.16	3.10	17.33	11.37
37	0.0002	3.63	3921	56.36	0.08	1.48	9.67	43.64	0.08	1.48	22.10	6.91
25	0.0002	2.44	2344	45.42	0.07	1.32	6.76	54.58	0.07	1.32	12.35	3.44
-25	0.0002	3.08	1049	28.66	0.47	9.10	1.14	71.34	0.47	9.09	1.60	3.08
Total	0.0066	100	1463	40.03	5.13	100	2.84	59.97	5.13	100	4.73	100

Table 45: Metallurgical balance of laboratory Knelson concentrator (Test 26)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	FEED (Pilot Knelson tails) % Weight	FEED (Pilot Knelson tails) Grade (g/t)	FEED (Pilot Knelson tails) Dist'n (%)
600	8.88	9.89	16	17.29	628	7.56	1.11	82.71	637	7.58	1.33	1.45
425	13.27	14.78	15	7.52	928	11.17	2.71	92.48	941	11.20	2.89	4.65
300	17.20	19.16	190	60.93	1175	14.14	1.78	39.07	1192	14.20	4.50	9.18
212	18.79	20.93	255	54.97	1661	19.99	2.37	45.03	1680	20.00	5.20	14.94
150	16.28	18.14	335	55.14	1298	15.62	3.41	44.86	1315	15.65	7.51	16.91
106	9.47	10.55	615	60.11	793	9.54	4.87	39.89	802	9.55	12.06	16.57
75	3.57	3.98	1120	57.76	412	4.96	7.10	42.24	415	4.95	16.66	11.85
53	1.43	1.59	2534	69.14	288	3.46	5.62	30.86	289	3.44	18.14	8.97
37	0.54	0.60	4301	87.46	131	1.58	2.54	12.54	132	1.57	20.16	4.55
25	0.220	0.25	7829	87.70	117	1.41	2.06	12.30	118	1.40	16.70	3.36
-25	0.110	0.12	14320	35.62	879	10.57	3.24	64.38	879	10.46	5.03	7.57
Total	89.76	100	367	56.36	8310	100	3.07	43.64	8400	100	6.95	100

Table 46: Metallurgical balance of pilot Knelson concentrator (Test 26)

Size (µm)	CONCENTRATE Weight (Tons)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (Tons)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED Weight (Tons)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	0.0003	13.12	4634	94.69	0.39	7.58	0.23	5.31	0.39	7.59	4.32	4.06
425	0.0004	15.68	4575	93.77	0.58	11.20	0.22	6.23	0.58	11.21	3.49	4.84
300	0.0005	18.53	4846	54.10	0.73	14.20	2.74	45.90	0.73	14.20	5.97	10.50
212	0.0005	18.60	4947	45.13	1.03	20.00	2.86	54.87	1.03	20.00	5.20	12.89
150	0.0004	15.78	6604	45.09	0.80	15.65	4.14	54.91	0.80	15.65	7.54	14.62
106	0.0003	9.77	10097	42.11	0.49	9.55	7.25	57.89	0.49	9.55	12.52	14.82
75	0.0001	4.68	22834	53.41	0.25	4.95	9.62	46.59	0.25	4.95	20.64	12.65
53	0.0001	2.10	35351	46.79	0.18	3.44	12.54	53.21	0.18	3.44	23.56	10.04
37	0.0000	0.90	63869	51.40	0.08	1.57	17.63	48.60	0.08	1.57	36.26	7.04
25	0.0000	0.38	84584	44.79	0.07	1.40	14.64	55.21	0.07	1.40	26.51	4.60
-25	0.0000	0.45	57463	41.39	0.54	10.46	1.79	58.61	0.54	10.45	3.06	3.96
Total	0.0026	100	8140	51.47	5.14	100	3.92	48.53	5.14	100	8.07	100

Table 47: Metallurgical balance of laboratory Knelson concentrator (Test 11T1)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails-1)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.31	10.02	182	69.38	960	8.08	0.78	30.62	969	8.10	2.52	4.68
425	12.84	13.83	27	13.51	1396	11.75	1.59	86.49	1409	11.77	1.82	4.92
300	16.84	18.13	118	19.56	1748	14.71	4.66	80.44	1765	14.74	5.74	19.40
212	18.84	20.29	231	41.40	2404	20.24	2.56	58.60	2423	20.24	4.33	20.13
150	16.66	17.94	235	56.83	1845	15.54	1.61	43.17	1862	15.55	3.70	13.19
106	10.34	11.13	224	45.26	1081	9.10	2.59	54.74	1091	9.11	4.69	9.80
75	4.37	4.71	341	41.03	577	4.86	3.71	58.97	581	4.86	6.24	6.96
53	2.01	2.16	698	43.21	394	3.32	4.68	56.79	396	3.31	8.20	6.23
37	0.90	0.97	1246	57.74	188	1.58	4.36	42.26	188	1.57	10.27	3.71
25	0.34	0.37	2167	46.11	186	1.57	4.65	53.89	186	1.56	8.61	3.08
-25	0.42	0.45	2800	28.63	1100	9.26	2.68	71.37	1101	9.19	3.75	7.92
Total	92.87	100	221	39.34	11879	100	2.66	60.66	11972	100	4.36	100

Table 48: Metallurgical balance of laboratory Knelson concentrator (Test 11T2)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails-2)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.12	11.04	11	2.50	900	7.91	4.7	97.50	910	7.93	4.81	9.34
425	13.01	14.19	17	5.40	1378	12.11	2.8	94.60	1391	12.13	2.94	8.74
300	16.21	17.68	110	18.30	1722	15.13	4.6	81.70	1738	15.15	5.61	20.83
212	17.87	19.49	119	37.88	2329	20.47	1.5	62.12	2347	20.46	2.40	12.00
150	15.71	17.14	138	33.81	1741	15.30	2.4	66.19	1757	15.32	3.64	13.64
106	9.98	10.89	187	43.39	992	8.72	2.5	56.61	1002	8.73	4.30	9.20
75	4.54	4.95	311	42.57	532	4.68	3.6	57.43	537	4.68	6.18	7.08
53	2.19	2.39	511	43.11	374	3.29	4.0	56.89	376	3.28	6.90	5.54
37	1.06	1.15	880	59.69	183	1.61	3.4	40.31	184	1.61	8.46	3.32
25	0.453	0.49	1495	50.55	173	1.52	3.8	49.45	173	1.51	7.72	2.86
-25	0.535	0.58	2023	30.96	1054	9.26	2.3	69.04	1054	9.19	3.32	7.46
Total	91.67	100	147	28.81	11378	100	2.93	71.19	11470	100	4.09	100

Table 49: Metallurgical balance of laboratory Knelson concentrator (Test 11T3)

Size	CONCENTRATE				TAILS				FEED (Pilot Knleson tails-3)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.40	10.15	10	2.94	867	7.33	3.68	97.06	877	7.35	3.75	6.31
425	12.86	13.88	96	32.52	1311	11.08	1.95	67.48	1324	11.10	2.86	7.27
300	16.51	17.82	131	37.51	1663	14.05	2.16	62.49	1680	14.08	3.42	11.03
212	18.32	19.78	152	46.87	2338	19.75	1.35	53.13	2357	19.75	2.52	11.40
150	16.19	17.48	197	36.72	1847	15.60	2.97	63.28	1863	15.62	4.65	16.64
106	10.30	11.12	364	60.19	1097	9.27	2.26	39.81	1107	9.28	5.62	11.95
75	4.86	5.25	550	59.63	598	5.05	3.03	40.37	603	5.05	7.45	8.61
53	2.19	2.36	1121	49.74	438	3.70	5.66	50.26	441	3.69	11.20	9.48
37	1.01	1.09	1657	65.53	216	1.83	4.07	34.47	217	1.82	11.75	4.90
25	0.433	0.47	2331	57.32	193	1.63	3.90	42.68	193	1.62	9.12	3.38
-25	0.565	0.61	2248	26.96	1269	10.72	2.71	73.04	1269	10.64	3.71	9.03
Total	92.64	100	241	42.76	11837	100	2.52	57.24	11930	100	4.37	100

Table 50: Metallurgical balance of laboratory Knelson concentrator (Test 11T4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.42	10.17	10	2.94	867	7.33	3.68	97.06	877	7.35	3.75	6.31
425	12.86	13.88	96	32.52	1311	11.08	1.95	67.48	1324	11.10	2.86	7.27
300	16.51	17.82	131	37.51	1663	14.05	2.16	62.49	1680	14.08	3.42	11.03
212	18.32	19.78	152	46.87	2338	19.75	1.35	53.13	2357	19.75	2.52	11.40
150	16.19	17.48	197	36.72	1847	15.60	2.97	63.28	1863	15.62	4.65	16.64
106	10.30	11.12	364	60.19	1097	9.27	2.26	39.81	1107	9.28	5.62	11.95
75	4.86	5.25	550	59.63	598	5.05	3.03	40.37	603	5.05	7.45	8.61
53	2.24	2.42	1121	50.30	438	3.70	5.66	49.70	441	3.69	11.33	9.58
37	1.01	1.09	1657	65.53	216	1.83	4.07	34.47	217	1.82	11.75	4.90
25	0.433	0.47	2331	57.32	193	1.63	3.90	42.68	193	1.62	9.12	3.38
-25	0.565	0.61	2248	26.96	1269	10.72	2.71	73.04	1269	10.64	3.71	9.03
Total	92.71	100	241	42.82	11837	100	2.52	57.18	11930	100	4.37	100

Table 51: Metallurgical balance of laboratory Knelson concentrator (Test 11F1+F2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-1) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.83	8.18	19	13.69	988	6.85	0.9	86.31	996	6.86	1.07	0.83
425	12.26	12.81	420	69.95	1638	11.37	1.4	30.05	1651	11.37	4.46	5.73
300	17.07	17.83	650	71.54	2186	15.16	2.0	28.46	2203	15.18	7.04	12.08
212	20.06	20.95	306	60.95	3099	21.50	1.3	39.05	3119	21.49	3.23	7.85
150	18.38	19.20	664	77.10	2324	16.12	1.6	22.90	2342	16.14	6.76	12.33
106	11.70	12.22	1311	76.12	1322	9.17	3.6	23.88	1334	9.19	15.11	15.69
75	5.10	5.33	4879	88.31	708	4.91	4.7	11.69	713	4.92	39.50	21.94
53	2.22	2.32	4534	85.45	487	3.38	3.5	14.55	489	3.37	24.08	9.17
37	0.79	0.82	8360	84.49	229	1.59	5.3	15.51	230	1.58	33.93	6.06
25	0.202	0.21	14653	72.27	193	1.34	5.9	27.73	193	1.33	21.19	3.18
-25	0.134	0.14	22136	44.90	1242	8.62	2.9	55.10	1242	8.56	5.32	5.14
Total	95.74	100	1019	75.94	14415	100	2.14	24.06	14511	100	8.85	100

Table 52: Metallurgical balance of laboratory Knelson concentrator (Test 11F3+F4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson feed-2) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.08	8.63	181	76.19	672	6.47	0.7	23.81	680	6.48	2.82	2.34
425	12.57	13.43	301	70.26	1098	10.56	1.5	29.74	1110	10.58	4.85	6.57
300	16.73	17.88	130	49.71	1491	14.34	1.5	50.29	1508	14.38	2.91	5.35
212	19.45	20.78	313	61.40	2164	20.81	1.8	38.60	2183	20.81	4.54	12.10
150	17.68	18.89	587	78.72	1669	16.05	1.7	21.28	1686	16.07	7.81	16.06
106	11.22	11.99	1015	79.84	968	9.31	3.0	20.16	979	9.33	14.57	17.39
75	4.83	5.16	1799	82.05	517	4.97	3.7	17.95	521	4.97	20.31	12.91
53	2.05	2.19	3306	76.08	354	3.40	6.0	23.92	356	3.39	25.03	10.86
37	0.67	0.72	6482	80.93	173	1.66	6.0	19.07	173	1.65	31.08	6.57
25	0.170	0.18	12463	67.94	155	1.49	6.5	32.06	155	1.48	20.13	3.81
-25	0.129	0.14	14864	38.67	1138	10.94	2.7	61.33	1138	10.85	4.35	6.04
Total	93.58	100	632	72.11	10397	100	2.20	27.89	10491	100	7.82	100

Table 53: Metallurgical balance of pilot Knelson concentrator (Test 11)

Size (µm)	CONCENTRATE				TAILS				FEED			
	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0003	9.21	5792	80.05	0.78	8.10	0.55	19.95	0.78	8.10	2.76	4.11
425	0.0004	13.23	5670	79.35	1.14	11.77	0.56	20.65	1.14	11.77	2.69	5.83
300	0.0005	16.22	8832	73.45	1.42	14.74	1.18	26.55	1.42	14.74	4.43	12.02
212	0.0006	18.44	5953	58.86	1.95	20.24	1.27	41.14	1.95	20.24	3.09	11.49
150	0.0006	18.25	14858	77.52	1.50	15.55	1.69	22.48	1.50	15.55	7.53	21.56
106	0.0003	10.23	8240	53.32	0.88	9.11	2.71	46.68	0.88	9.11	5.81	9.74
75	0.0002	5.46	19592	67.48	0.47	4.86	3.55	32.52	0.47	4.86	10.92	9.76
53	0.0002	5.37	24199	74.36	0.32	3.31	4.53	25.64	0.32	3.31	17.67	10.76
37	0.0001	1.61	60240	75.51	0.15	1.57	6.69	24.49	0.15	1.57	27.29	7.90
25	0.0000	0.71	44056	59.36	0.15	1.56	4.61	40.64	0.15	1.56	11.33	3.25
-25	0.0000	1.28	23523	51.77	0.89	9.19	1.02	48.23	0.89	9.19	2.12	3.59
Total	0.0032	100	11318	69.75	9.65	100	1.66	30.25	9.65	100	5.44	100

Table 54: Metallurgical balance of laboratory Knelson concentrator (Test 15T1)

Size (µm)	CONCENTRATE				TAILS				FEED (Pilot Knleson tails-1)			
	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.28	8.66	347	86.78	797	6.20	0.55	13.22	805	6.22	4.12	6.81
425	12.86	13.45	174	46.73	1383	10.76	1.84	53.27	1396	10.78	3.42	9.82
300	17.34	18.14	127	55.57	1928	15.01	0.91	44.43	1946	15.03	2.03	8.12
212	20.00	20.92	179	60.75	2824	21.97	0.82	39.25	2844	21.97	2.07	12.12
150	18.23	19.07	189	40.70	2263	17.61	2.22	59.30	2282	17.62	3.71	17.41
106	11.20	11.72	334	51.63	1257	9.78	2.79	48.37	1268	9.79	5.72	14.90
75	4.56	4.77	593	51.19	624	4.85	4.13	48.81	628	4.85	8.40	10.85
53	1.77	1.85	1102	50.67	415	3.23	4.57	49.33	417	3.22	9.23	7.91
37	0.70	0.74	1797	68.38	187	1.46	3.12	31.62	188	1.45	9.83	3.79
25	0.290	0.30	2614	60.06	175	1.36	2.88	39.94	175	1.35	7.20	2.59
-25	0.357	0.37	2908	37.53	998	7.76	1.73	62.47	998	7.71	2.77	5.68
Total	95.59	100	270	53.00	12851	100	1.78	47.00	12947	100	3.76	100

Table 55: Metallurgical balance of laboratory Knelson concentrator (Test 15T2)

Size (µm)	CONCENTRATE				TAILS				FEED (Pilot Knelson tails-2)			
	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.37	8.79	116	30.87	882	6.92	2.5	69.13	891	6.93	3.53	9.15
425	12.44	13.06	68	14.41	1369	10.73	3.7	85.59	1382	10.75	4.24	17.05
300	16.72	17.56	67	31.95	1830	14.34	1.3	68.05	1846	14.37	1.89	10.18
212	19.79	20.78	58	32.56	2681	21.01	0.9	67.44	2701	21.01	1.31	10.30
150	18.42	19.34	75	31.85	2132	16.71	1.4	68.15	2151	16.73	2.02	12.67
106	11.21	11.77	132	40.51	1231	9.65	1.8	59.49	1242	9.66	2.93	10.61
75	4.70	4.93	236	37.18	626	4.90	3.0	62.82	631	4.91	4.72	8.68
53	2.03	2.13	413	35.13	414	3.24	3.7	64.87	416	3.24	5.74	6.95
37	0.85	0.89	767	50.80	199	1.56	3.2	49.20	199	1.55	6.44	3.74
25	0.331	0.35	1444	43.66	171	1.34	3.6	56.34	171	1.33	6.40	3.19
-25	0.378	0.40	2137	31.41	1224	9.59	1.4	68.59	1224	9.53	2.10	7.49
Total	95.24	100	114	31.53	12759	100	1.84	68.47	12854	100	2.67	100

Table 56: Metallurgical balance of laboratory Knelson concentrator (Test 15T3)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-3) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.88	9.49	8	23.23	729	6.50	0.33	76.77	738	6.53	0.42	0.90
425	12.15	12.99	17	18.41	1172	10.45	0.79	81.59	1184	10.47	0.96	3.26
300	16.12	17.23	115	51.30	1555	13.86	1.13	48.70	1571	13.89	2.30	10.37
212	18.94	20.24	109	56.00	2284	20.37	0.71	44.00	2303	20.37	1.60	10.59
150	17.87	19.10	114	44.49	1856	16.55	1.37	55.51	1873	16.57	2.44	13.16
106	11.39	12.17	236	50.70	1111	9.91	2.35	49.30	1123	9.93	4.72	15.22
75	4.81	5.14	509	56.75	573	5.11	3.26	43.25	578	5.11	7.47	12.41
53	1.93	2.06	1088	52.11	390	3.48	4.95	47.89	392	3.46	10.28	11.58
37	0.75	0.80	1901	72.42	160	1.43	3.38	27.58	161	1.42	12.20	5.64
25	0.30	0.32	2732	51.87	196	1.75	3.87	48.13	197	1.74	8.03	4.54
-25	0.43	0.46	2591	25.84	1188	10.59	2.68	74.16	1188	10.51	3.61	12.34
Total	93.57	100	180	48.33	11214	100	1.60	51.67	11308	100	3.08	100

Table 57: Metallurgical balance of laboratory Knelson concentrator (Test 15T4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.11	9.76	11	16.57	756	6.09	0.68	83.43	765	6.11	0.81	1.22
425	13.06	13.99	76	41.57	1320	10.63	1.06	58.43	1333	10.65	1.80	4.73
300	16.85	18.06	187	46.12	1917	15.44	1.92	53.88	1934	15.46	3.53	13.50
212	19.30	20.68	107	20.70	2327	18.74	3.40	79.30	2347	18.76	4.25	19.72
150	17.52	18.77	204	29.76	2231	17.97	3.78	70.24	2249	17.97	5.34	23.73
106	10.38	11.12	282	36.51	1287	10.37	3.96	63.49	1298	10.37	6.19	15.87
75	4.11	4.40	462	43.36	645	5.19	3.85	56.64	649	5.18	6.75	8.66
53	1.64	1.76	832	63.77	369	2.97	2.10	36.23	371	2.96	5.77	4.23
37	0.71	0.76	1293	78.36	240	1.93	1.06	21.64	241	1.92	4.88	2.32
25	0.312	0.33	1733	81.07	160	1.29	0.79	18.93	160	1.28	4.17	1.32
-25	0.330	0.35	2550	35.36	1166	9.39	1.32	64.64	1167	9.33	2.04	4.71
Total	93.32	100	197	36.34	12419	100	2.59	63.66	12512	100	4.04	100

Table 58: Metallurgical balance of laboratory Knelson concentrator (Test 15F1+F2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson feed-1) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.44	8.71	363	90.79	819	6.47	0.38	9.21	827	6.49	4.08	3.04
425	12.00	12.38	314	75.45	1319	10.42	0.93	24.55	1331	10.44	3.75	4.50
300	16.25	16.77	557	86.86	1756	13.87	0.78	13.14	1772	13.89	5.88	9.39
212	19.40	20.02	378	79.81	2609	20.62	0.71	20.19	2629	20.61	3.49	8.27
150	18.60	19.19	381	61.02	2124	16.78	2.13	38.98	2143	16.80	5.42	10.46
106	12.31	12.70	943	82.48	1252	9.89	1.97	17.52	1264	9.91	11.14	12.69
75	5.51	5.68	2621	86.25	645	5.10	3.57	13.75	651	5.10	25.74	15.09
53	2.39	2.47	5893	87.13	429	3.39	4.85	12.87	431	3.38	37.48	14.57
37	0.98	1.01	10686	92.51	204	1.61	4.16	7.49	205	1.61	55.29	10.23
25	0.45	0.46	11668	87.20	181	1.43	4.25	12.80	181	1.42	33.12	5.41
-25	0.60	0.61	7384	62.49	1319	10.42	2.00	37.51	1319	10.35	5.33	6.34
Total	96.93	100	934	81.62	12657	100	1.61	18.38	12754	100	8.70	100

Table 59: Metallurgical balance of laboratory Knelson concentrator (Test 15F3+F4)

Size	CONCENTRATE				TAILS				FEED (Pilot Knleson feed-2)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.52	7.76	9	8.71	858	6.35	0.86	91.29	865	6.36	0.94	0.80
425	11.73	12.10	232	67.95	1391	10.30	0.92	32.05	1403	10.31	2.85	3.96
300	16.13	16.64	527	82.34	1867	13.82	0.98	17.66	1883	13.84	5.48	10.19
212	19.58	20.20	367	60.30	2775	20.54	1.71	39.70	2794	20.54	4.27	11.78
150	19.01	19.61	712	71.97	2301	17.03	2.29	28.03	2320	17.05	8.11	18.59
106	12.79	13.19	872	72.36	1367	10.12	3.11	27.64	1380	10.14	11.16	15.22
75	5.74	5.92	1914	80.37	717	5.31	3.74	19.63	723	5.31	18.92	13.50
53	2.41	2.49	3753	83.60	475	3.52	3.73	16.40	477	3.51	22.66	10.69
37	1.05	1.08	5787	89.00	222	1.65	3.36	11.00	223	1.64	30.41	6.71
25	0.43	0.45	6324	85.70	204	1.51	2.24	14.30	205	1.50	15.60	3.15
-25	0.54	0.56	5494	54.47	1333	9.86	1.88	45.53	1333	9.80	4.12	5.42
Total	96.93	100	773	74.05	13510	100	1.94	25.95	13607	100	7.44	100

Table 60: Metallurgical balance of pilot Knelson concentrator (Test 15)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0003	8.79	6702	72.98	0.64	6.45	1.26	27.02	0.64	6.45	4.65	4.81
425	0.0005	13.08	6035	77.26	1.06	10.66	0.81	22.74	1.06	10.66	3.56	6.08
300	0.0006	16.24	6719	70.75	1.46	14.69	1.14	29.25	1.46	14.69	3.90	9.19
212	0.0007	18.31	12099	82.16	2.04	20.53	0.87	17.84	2.04	20.53	4.88	16.06
150	0.0006	17.39	11602	78.07	1.71	17.22	1.22	21.93	1.71	17.22	5.57	15.39
106	0.0004	10.01	14695	71.44	0.99	9.94	2.20	28.56	0.99	9.94	7.69	12.26
75	0.0002	5.34	19759	70.42	0.50	5.01	3.28	29.58	0.50	5.01	11.09	8.92
53	0.0002	5.47	36776	85.57	0.32	3.22	3.91	14.43	0.32	3.22	27.09	14.00
37	0.0001	1.76	47605	78.43	0.16	1.59	5.41	21.57	0.16	1.59	25.05	6.38
25	0.0000	0.89	45900	74.46	0.14	1.43	3.67	25.54	0.14	1.43	14.36	3.29
-25	0.0001	2.72	14763	66.11	0.92	9.27	0.83	33.89	0.92	9.26	2.44	3.62
Total	0.0037	100	12891	76.79	9.92	100	1.45	23.21	9.93	100	6.23	100

Table 61: Metallurgical balance of laboratory Knelson concentrator (Test 18T1)

Size	CONCENTRATE				TAILS				FEED (Pilot Knleson tails-1)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.28	7.58	24	37.83	787	6.63	0.37	62.17	794	6.64	0.59	1.17
425	12.60	13.12	100	30.26	1323	11.16	2.19	69.74	1336	11.17	3.11	10.41
300	17.15	17.86	190	68.14	1879	15.84	0.81	31.86	1896	15.85	2.52	11.96
212	20.18	21.01	129	44.99	2249	18.95	1.42	55.01	2269	18.97	2.56	14.54
150	18.93	19.71	167	45.13	2047	17.25	1.88	54.87	2066	17.27	3.39	17.57
106	11.79	12.28	274	55.25	1133	9.55	2.31	44.75	1145	9.58	5.11	14.65
75	4.71	4.90	449	46.89	568	4.79	4.21	53.11	573	4.79	7.86	11.29
53	1.98	2.06	570	49.93	342	2.88	3.31	50.07	344	2.88	6.57	5.66
37	0.80	0.84	953	53.33	232	1.96	2.89	46.67	233	1.95	6.17	3.60
25	0.311	0.32	1406	45.72	164	1.39	3.16	54.28	165	1.38	5.81	2.40
-25	0.304	0.32	1755	19.77	1139	9.60	1.90	80.23	1139	9.52	2.37	6.75
Total	96.04	100	194	46.78	11863	100	1.79	53.22	11959	100	3.34	100

Table 62: Metallurgical balance of laboratory Knelson concentrator (Test 18T2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-2) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.01	7.21	9	5.86	713	5.64	1.4	94.14	720	5.66	1.43	1.85
425	11.68	12.01	44	26.12	1328	10.52	1.1	73.88	1339	10.53	1.46	3.51
300	16.56	17.03	159	61.40	1952	15.46	0.9	38.60	1969	15.47	2.18	7.71
212	20.25	20.82	371	70.82	2364	18.72	1.3	29.18	2384	18.74	4.45	19.03
150	19.62	20.18	228	52.03	2218	17.56	1.9	47.97	2237	17.58	3.84	15.41
106	12.77	13.13	500	65.01	1263	10.00	2.7	34.99	1276	10.03	7.70	17.61
75	5.49	5.65	748	60.44	645	5.10	4.2	39.56	650	5.11	10.45	12.18
53	2.28	2.34	1231	60.80	375	2.97	4.8	39.20	377	2.96	12.25	8.28
37	0.90	0.92	1928	63.33	247	1.96	4.0	36.67	248	1.95	10.98	4.89
25	0.336	0.35	3252	64.27	168	1.33	3.6	35.73	169	1.33	10.08	3.05
-25	0.352	0.36	3833	37.24	1354	10.72	1.7	62.76	1354	10.64	2.68	6.50
Total	97.24	100	336	58.57	12627	100	1.83	41.43	12724	100	4.38	100

Table 63: Metallurgical balance of laboratory Knelson concentrator (Test 18T3)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-3) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.19	7.61	80	62.32	658	5.08	0.5	37.68	665	5.10	1.39	1.57
425	12.27	12.98	399	79.40	1395	10.78	0.9	20.60	1408	10.80	4.38	10.46
300	16.80	17.77	265	65.44	2011	15.54	1.2	34.56	2028	15.55	3.36	11.55
212	19.37	20.49	173	58.42	2383	18.41	1.0	41.58	2402	18.42	2.39	9.72
150	17.78	18.81	284	52.96	2229	17.22	2.0	47.04	2246	17.23	4.24	16.16
106	11.60	12.27	421	67.64	1270	9.82	1.8	32.36	1282	9.83	5.63	12.26
75	5.21	5.51	850	68.49	653	5.04	3.1	31.51	658	5.05	9.82	10.97
53	2.27	2.40	1748	73.42	391	3.02	3.7	26.58	394	3.02	13.73	9.17
37	1.00	1.05	2965	75.92	263	2.03	3.6	24.08	264	2.03	14.73	6.61
25	0.422	0.45	3938	75.09	184	1.42	3.0	24.91	184	1.41	12.02	3.76
-25	0.626	0.66	3558	48.70	1505	11.63	1.6	51.30	1506	11.55	3.04	7.77
Total	94.54	100	407	65.24	12942	100	1.58	34.76	13037	100	4.52	100

Table 64: Metallurgical balance of laboratory Knelson concentrator (Test 18T4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	6.80	7.26	12	12.88	985	6.76	0.6	87.12	991	6.76	0.65	1.28
425	12.21	13.04	147	26.82	1776	12.19	2.8	73.18	1789	12.20	3.73	13.30
300	17.47	18.66	230	56.76	2425	16.65	1.3	43.24	2443	16.66	2.89	14.08
212	20.26	21.64	193	60.10	2738	18.79	1.0	39.90	2758	18.81	2.36	12.99
150	18.13	19.36	189	51.17	2399	16.46	1.4	48.83	2417	16.48	2.76	13.32
106	10.79	11.52	346	58.89	1276	8.76	2.0	41.11	1287	8.77	4.92	12.62
75	4.47	4.77	586	58.65	636	4.37	2.9	41.35	641	4.37	6.97	8.90
53	1.87	2.00	1189	61.69	380	2.61	3.6	38.31	382	2.61	9.43	7.18
37	0.82	0.88	2017	62.14	266	1.82	3.8	37.86	267	1.82	10.01	5.32
25	0.349	0.37	2919	63.18	185	1.27	3.2	36.82	186	1.27	8.67	3.21
-25	0.465	0.50	2980	35.41	1503	10.32	1.7	64.59	1504	10.26	2.60	7.79
Total	93.64	100	276	51.52	14570	100	1.67	48.48	14664	100	3.42	100

Table 65: Metallurgical balance of laboratory Knelson concentrator (Test 18F1+F2)

	CONCENTRATE				TAILS				FEED (pilot Knelson feed-1)			
Size (µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	5.99	6.10	741	90.62	718	5.48	0.64	9.38	724	5.49	6.77	4.63
425	12.24	12.46	246	54.68	1432	10.94	1.74	45.32	1444	10.95	3.81	5.19
300	17.23	17.55	373	53.99	1937	14.79	2.83	46.01	1954	14.82	6.10	11.25
212	20.75	21.13	520	80.48	2784	21.26	0.94	19.52	2805	21.26	4.78	12.65
150	19.56	19.92	513	58.70	2204	16.84	3.20	41.30	2224	16.86	7.68	16.12
106	12.82	13.06	854	75.99	1281	9.78	2.70	24.01	1294	9.81	11.13	13.60
75	5.48	5.58	1764	78.11	674	5.15	4.02	21.89	680	5.15	18.21	11.69
53	2.32	2.36	3326	74.52	443	3.39	5.95	25.48	446	3.38	23.23	9.77
37	0.99	1.00	5506	79.10	208	1.59	6.89	20.90	209	1.58	32.81	6.48
25	0.37	0.38	6489	69.40	179	1.36	5.98	30.60	179	1.36	19.50	3.29
-25	0.45	0.46	6162	48.90	1232	9.41	2.34	51.10	1233	9.35	4.58	5.33
Total	98.20	100	750	69.51	13093	100	2.47	30.49	13191	100	8.03	100

Table 66: Metallurgical balance of laboratory Knelson concentrator (Test 18F3+F4)

	CONCENTRATE				TAILS				FEED (Pilot Knleson feed-2)			
Size (µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.98	8.28	263	66.02	826	6.56	1.31	33.98	834	6.57	3.82	3.52
425	12.86	13.34	109	45.66	1376	10.92	1.21	54.34	1389	10.94	2.21	3.39
300	16.93	17.56	478	84.83	1810	14.36	0.80	15.17	1827	14.39	5.22	10.55
212	19.45	20.18	342	62.31	2582	20.49	1.56	37.69	2601	20.49	4.11	11.82
150	17.93	18.60	705	78.72	2023	16.06	1.69	21.28	2041	16.08	7.87	17.76
106	11.90	12.34	883	78.69	1172	9.30	2.43	21.31	1183	9.32	11.29	14.77
75	5.18	5.37	1726	81.10	615	4.88	3.39	18.90	620	4.88	17.78	12.19
53	2.14	2.22	3466	77.73	419	3.33	5.07	22.27	421	3.32	22.65	10.55
37	0.96	1.00	5071	85.33	206	1.63	4.07	14.67	207	1.63	27.62	6.32
25	0.43	0.44	5457	75.82	188	1.50	3.95	24.18	189	1.49	16.30	3.40
-25	0.64	0.66	3891	47.96	1383	10.98	1.95	52.04	1384	10.90	3.75	5.73
Total	96.40	100	700	74.60	12600	100	1.82	25.40	12696	100	7.12	100

Table 67: Metallurgical balance of pilot Knelson concentrator (Test 18)

	CONCENTRATE				TAILS				FEED			
Size (µm)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (Tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0004	5.55	2008	84.79	0.55	6.04	0.28	15.21	0.55	6.04	1.86	2.32
425	0.0006	8.35	1817	44.62	1.01	11.17	1.44	55.38	1.01	11.17	2.61	6.01
300	0.0009	11.44	1976	41.41	1.43	15.88	1.73	58.59	1.44	15.88	2.94	9.65
212	0.0012	15.03	2837	52.38	1.69	18.74	1.77	47.62	1.69	18.73	3.72	14.39
150	0.0013	17.01	2557	54.81	1.55	17.14	1.79	45.19	1.55	17.14	3.96	14.03
106	0.0010	12.40	3267	49.92	0.86	9.55	3.64	50.08	0.86	9.55	7.27	14.34
75	0.0006	8.04	3629	49.70	0.44	4.83	5.24	50.30	0.44	4.83	10.41	10.39
53	0.0008	10.43	5144	70.40	0.26	2.87	6.74	29.60	0.26	2.87	22.71	13.47
37	0.0003	4.16	6441	62.88	0.17	1.94	7.01	37.12	0.18	1.94	18.84	7.54
25	0.0002	2.37	5173	56.60	0.12	1.35	5.97	43.40	0.12	1.35	13.74	3.82
-25	0.0004	5.22	2020.5	46.26	0.95	10.49	1.00	53.74	0.95	10.49	1.86	4.03
Total	0.0077	100	3080	54.45	9.03	100	2.21	45.55	9.04	100	4.84	100

Appendix 3 LKC and pilot Knelson concentrator metallurgical balances: campaign 2

Appendix 3 LKC and pilot Knelson concentrator metallurgical balances: campaign 2

Table 68 : Metallurgical balance of laboratory Knelson concentrator (Test 1)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.18	10.44	311	48.17	1281	8.80	2.40	51.83	1290	8.81	4.60	4.28
425	11.52	13.10	213	44.55	1580	10.86	1.93	55.45	1592	10.87	3.46	3.97
300	16.08	18.29	712	77.80	2302	15.81	1.42	22.20	2318	15.83	6.35	10.62
212	18.65	21.21	769	58.76	2742	18.83	3.67	41.24	2760	18.85	8.84	17.60
150	17.11	19.46	1031	60.54	2381	16.35	4.83	39.46	2398	16.37	12.15	21.02
106	8.14	9.26	1558	68.55	1295	8.90	4.49	31.45	1303	8.90	14.19	13.34
75	4.25	4.83	2788	75.31	769	5.28	5.05	24.69	773	5.28	20.34	11.35
53	1.89	2.15	4680	79.30	415	2.85	5.56	20.70	417	2.85	26.74	8.05
37	0.85	0.97	6163	77.38	275	1.89	5.57	22.62	276	1.88	24.54	4.88
25	0.247	0.28	7218	74.79	122	0.84	4.91	25.21	123	0.84	19.44	1.72
-25	0.014	0.02	8936	2.83	1395	9.58	3.08	97.17	1395	9.52	3.17	3.19
Total	87.93	100	1015	64.38	14556	100	3.39	35.62	14644	100	9.47	100

Table 69: Metallurgical balance of pilot Knelson concentrator (Test 1)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.000410	12.35	12201	81.95	0.50	8.81	2.22	18.05	0.50	8.81	12.3	6.57
425	0.000512	15.41	13166	87.70	0.61	10.87	1.54	12.30	0.61	10.87	12.5	8.27
300	0.000585	17.63	14041	65.04	0.89	15.83	4.94	34.96	0.89	15.83	14.1	13.60
212	0.000634	19.09	13108	60.04	1.06	18.85	5.19	39.96	1.07	18.85	13.0	14.90
150	0.000567	17.07	15306	56.05	0.92	16.37	7.36	43.95	0.93	16.37	16.7	16.66
106	0.000270	8.14	25328	58.33	0.50	8.90	9.73	41.67	0.50	8.90	23.3	12.63
75	0.000128	3.86	37123	51.00	0.30	5.28	15.32	49.00	0.30	5.28	31.2	10.04
53	0.000117	3.53	53048	64.58	0.16	2.85	21.21	35.42	0.16	2.85	59.8	10.37
37	0.000039	1.16	59361	53.15	0.11	1.88	18.99	46.85	0.11	1.88	40.5	4.64
25	0.000019	0.56	45675	55.20	0.05	0.84	14.54	44.80	0.05	0.84	32.4	1.65
-25	0.000040	1.20	14662	92.36	0.54	9.52	0.09	7.64	0.54	9.52	1.2	0.68
Total	0.003321	100	17614	62.95	5.65	100	6.10	37.05	5.65	100	16.4	100

Table 70: Metallurgical balance of laboratory Knelson concentrator (Test 2)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.09	9.33	566	67.62	1160	6.70	1.89	32.38	1168	6.72	5.80	4.06
425	11.93	13.76	774	71.77	1921	11.10	1.89	28.23	1933	11.12	6.65	7.72
300	17.32	19.98	1008	58.26	2875	16.62	4.35	41.74	2892	16.63	10.36	17.97
212	19.56	22.57	789	74.33	3232	18.68	1.65	25.67	3251	18.70	6.39	12.46
150	16.76	19.34	1261	75.25	2693	15.56	2.58	24.75	2710	15.58	10.36	16.84
106	7.46	8.61	2021	68.66	1452	8.39	4.74	31.34	1460	8.39	15.05	13.18
75	3.53	4.07	4257	74.99	884	5.11	5.67	25.01	888	5.10	22.58	12.02
53	1.35	1.56	7487	81.01	497	2.87	4.77	18.99	498	2.86	25.05	7.49
37	0.43	0.50	9746	79.53	342	1.98	3.18	20.47	343	1.97	15.51	3.19
25	0.112	0.13	13643	86.52	162	0.94	1.47	13.48	162	0.93	10.90	1.06
-25	0.129	0.15	14933	28.85	2083	12.04	2.28	71.15	2084	11.98	3.20	4.01
Total	86.68	100	1335	69.43	17300	100	2.94	30.57	17387	100	9.59	100

Table 71: Metallurgical balance of pilot Knelson concentrator (Test 2)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.000306	9.75	12492	66.95	0.48	6.72	3.92	33.05	0.48	6.72	11.9	5.83
425	0.000458	14.59	12067	59.22	0.80	11.12	4.78	40.78	0.80	11.12	11.7	9.53
300	0.000554	17.65	12317	48.69	1.19	16.63	6.04	51.31	1.19	16.63	11.8	14.32
212	0.000613	19.53	12350	54.34	1.34	18.70	4.75	45.66	1.34	18.70	10.4	14.23
150	0.000575	18.30	14744	49.31	1.12	15.58	7.80	50.69	1.12	15.58	15.4	17.54
106	0.000288	9.16	20613	48.82	0.60	8.39	10.33	51.18	0.60	8.40	20.2	12.40
75	0.000139	4.42	28640	39.08	0.37	5.10	16.93	60.92	0.37	5.10	27.8	10.38
53	0.000120	3.83	41305	54.40	0.21	2.86	20.29	45.60	0.21	2.87	44.5	9.33
37	0.000037	1.16	51573	51.95	0.14	1.97	12.34	48.05	0.14	1.97	25.7	3.71
25	0.000015	0.47	43831	50.80	0.07	0.93	9.43	49.20	0.07	0.93	19.2	1.31
-25	0.000035	1.12	17280	43.44	0.86	11.98	0.92	56.56	0.86	11.98	1.6	1.43
Total	0.003141	100	16003	51.29	7.17	100	6.66	48.71	7.17	100	13.7	100

Table 72: Metallurgical balance of laboratory Knelson concentrator (Test 3)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	6.00	6.55	1038	78.09	1071	6.21	1.63	21.91	1077	6.24	7.41	5.00
425	11.40	12.44	641	66.71	1904	11.03	1.91	33.29	1916	11.09	5.72	6.85
300	17.90	19.54	652	70.89	2906	16.84	1.65	29.11	2924	16.93	5.63	10.31
212	20.70	22.59	918	78.51	3310	19.18	1.57	21.49	3330	19.28	7.27	15.15
150	18.70	20.41	1144	72.86	2831	16.40	2.81	27.14	2849	16.50	10.30	18.38
106	8.70	9.49	1746	72.21	1530	8.86	3.82	27.79	1539	8.91	13.67	13.17
75	4.50	4.91	3070	72.39	917	5.32	5.75	27.61	922	5.34	20.70	11.95
53	1.90	2.07	4734	77.01	496	2.88	5.41	22.99	498	2.89	23.44	7.31
37	1.10	1.20	6467	79.35	340	1.97	5.44	20.65	341	1.97	26.28	5.61
25	0.338	0.37	6347	75.50	157	0.91	4.44	24.50	157	0.91	18.10	1.78
-25	0.392	0.43	7333	40.07	1797	10.41	2.39	59.93	1797	10.41	3.99	4.49
Total	91.63	100	1263	72.45	17259	100	2.55	27.55	17269	100	9.25	100

Table 73: Metallurgical balance of pilot Knelson concentrator (Test 3)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00035	10.33	8437	54.24	0.43	6.21	5.78	45.76	0.43	6.21	12.6	6.14
425	0.00052	15.35	9088	61.81	0.76	11.04	3.81	38.19	0.76	11.04	10.0	8.63
300	0.00061	18.08	9110	54.45	1.17	16.85	3.99	45.55	1.17	16.85	8.8	11.56
212	0.00065	19.26	9994	46.19	1.33	19.19	5.71	53.81	1.33	19.19	10.6	15.93
150	0.00061	17.92	12236	46.49	1.14	16.42	7.51	53.51	1.14	16.42	14.0	18.03
106	0.00031	9.06	16765	45.86	0.61	8.87	9.87	54.14	0.61	8.87	18.2	12.66
75	0.00014	4.27	23059	37.65	0.37	5.31	14.99	62.35	0.37	5.31	24.0	10.00
53	0.00012	3.45	35670	53.66	0.20	2.87	18.05	46.34	0.20	2.87	38.9	8.76
37	0.00003	0.97	47095	35.32	0.14	1.96	20.85	64.68	0.14	1.96	32.2	4.96
25	0.00001	0.39	39770	37.95	0.06	0.91	13.66	62.05	0.06	0.91	22.0	1.56
-25	0.00003	0.92	13529	26.72	0.72	10.36	1.60	73.28	0.72	10.35	2.2	1.77
Total	0.00338	100	12501	47.79	6.92	100	6.67	52.21	6.92	100	12.8	100

Table 74: Metallurgical balance of laboratory Knelson concentrator (Test 4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.81	8.54	274	68.92	799	5.08	1.21	31.08	807	5.10	3.85	2.33
425	11.23	12.28	593	71.97	1630	10.35	1.59	28.03	1641	10.36	5.64	6.93
300	17.12	18.72	594	67.36	2540	16.13	1.94	32.64	2558	16.15	5.90	11.32
212	20.54	22.46	757	68.69	3020	19.18	2.35	31.31	3041	19.20	7.44	16.96
150	18.56	20.30	904	66.03	2589	16.44	3.33	33.97	2608	16.46	9.74	19.04
106	8.58	9.38	1540	71.23	1404	8.92	3.80	28.77	1413	8.92	13.13	13.90
75	4.14	4.53	2630	71.42	834	5.30	5.22	28.58	838	5.29	18.19	11.43
53	1.74	1.90	4281	76.52	459	2.91	4.98	23.48	460	2.91	21.14	7.30
37	0.99	1.08	4928	76.26	320	2.03	4.76	23.74	321	2.02	19.98	4.80
25	0.354	0.39	4191	66.81	153	0.97	4.82	33.19	153	0.97	14.48	1.66
-25	0.382	0.42	5411	35.77	1998	12.69	1.86	64.23	1999	12.62	2.89	4.33
Total	91.45	100	998	68.41	15747	100	2.68	31.59	15838	100	8.42	100

Table 75: Metallurgical balance of pilot Knelson concentrator (Test 4)

Size (µm)	CONCENTRATE Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00019	5.39	12304	71.74	0.35	5.10	2.65	28.26	0.35	5.10	9.4	4.01
425	0.00033	9.18	12515	58.56	0.71	10.36	4.06	41.44	0.71	10.36	9.8	8.50
300	0.00045	12.63	11343	53.56	1.11	16.15	3.98	46.44	1.11	16.15	8.6	11.59
212	0.00074	20.73	10196	52.69	1.32	19.20	5.11	47.31	1.32	19.20	10.8	17.37
150	0.00074	20.74	9860	49.95	1.13	16.46	6.43	50.05	1.13	16.47	12.8	17.73
106	0.00047	13.17	10606	46.39	0.61	8.92	9.36	53.61	0.61	8.92	17.4	13.04
75	0.00026	7.28	13021	41.61	0.36	5.29	12.99	58.39	0.36	5.29	22.2	9.86
53	0.00023	6.43	19913	58.48	0.20	2.91	16.18	41.52	0.20	2.91	38.9	9.49
37	0.00006	1.80	28468	46.19	0.14	2.02	15.24	53.81	0.14	2.02	28.3	4.80
25	0.00003	0.84	26717	55.46	0.07	0.97	9.67	44.54	0.07	0.97	21.7	1.76
-25	0.00006	1.80	9823	41.24	0.87	12.62	1.03	58.76	0.87	12.61	1.8	1.86
Total	0.00355	100	11944	51.73	6.86	100	5.76	48.27	6.86	100	11.9	100

Table 76: Metallurgical balance of laboratory Knelson concentrator (Test 6)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knleson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.50	8.47	845	48.47	1211	7.24	5.56	51.53	1218	7.29	10.73	8.06
425	11.50	12.99	717	64.20	1728	10.34	2.66	35.80	1739	10.41	7.38	7.91
300	16.90	19.09	815	76.39	2560	15.32	1.66	23.61	2577	15.43	7.00	11.12
212	19.20	21.69	868	64.09	3038	18.17	3.08	35.91	3057	18.30	8.51	16.04
150	17.50	19.77	1231	76.94	2688	16.08	2.40	23.06	2706	16.20	10.35	17.26
106	8.30	9.37	1871	74.41	1463	8.76	3.65	25.59	1472	8.81	14.18	12.86
75	4.20	4.74	3084	78.13	867	5.19	4.18	21.87	871	5.21	19.04	10.22
53	1.90	2.15	4090	76.23	480	2.87	5.04	23.77	482	2.89	21.14	6.28
37	1.01	1.14	5416	78.93	347	2.07	4.23	21.07	348	2.08	19.99	4.29
25	0.27	0.30	6854	73.50	168	1.00	3.97	26.50	168	1.01	14.96	1.55
-25	0.25	0.28	10942	38.41	2165	12.95	2.04	61.59	2166	12.96	3.31	4.42
Total	88.53	100	1275	69.60	16715	100	2.95	30.40	16707	100	9.71	100

Table 77: Metallurgical balance of pilot Knelson concentrator (Test 6)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00034	10.52	9458	51.09	0.59	7.25	5.20	48.91	0.59	7.25	10.6	6.23
425	0.00044	13.65	9855	52.06	0.84	10.35	4.74	47.94	0.84	10.35	9.9	8.27
300	0.00051	15.94	9798	42.98	1.24	15.34	5.35	57.02	1.24	15.34	9.4	11.62
212	0.00056	17.49	10100	41.34	1.47	18.19	5.45	58.66	1.47	18.19	9.3	13.67
150	0.00055	17.30	15005	44.49	1.30	16.10	7.96	55.51	1.30	16.10	14.3	18.67
106	0.00032	9.86	17519	42.54	0.71	8.76	10.55	57.46	0.71	8.76	18.3	13.00
75	0.00018	5.50	22592	38.95	0.42	5.18	14.87	61.05	0.42	5.18	24.4	10.21
53	0.00017	5.39	32380	59.90	0.23	2.87	16.12	40.10	0.23	2.87	40.2	9.32
37	0.00005	1.65	47103	48.47	0.17	2.07	15.78	51.53	0.17	2.07	30.6	5.12
25	0.00002	0.77	35429	49.40	0.08	1.00	11.00	50.60	0.08	1.00	21.7	1.76
-25	0.00006	1.92	13031	37.71	1.04	12.89	1.27	62.29	1.04	12.88	2.0	2.13
Total	0.00320	100	14279	45.68	8.08	100	6.72	54.32	8.08	100	12.4	100

Table 78: Metallurgical balance of laboratory Knelson concentrator (Test 7)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	11.60	13.62	194	51.97	1178	7.82	1.77	48.03	1190	7.85	3.64	3.67
425	12.27	14.40	556	65.08	1591	10.56	2.30	34.92	1603	10.58	6.54	8.88
300	16.07	18.86	481	55.80	2301	15.28	2.66	44.20	2318	15.30	5.98	11.74
212	17.19	20.18	779	73.13	2722	18.07	1.81	26.87	2739	18.08	6.69	15.52
150	14.56	17.09	1034	72.12	2366	15.71	2.46	27.88	2381	15.71	8.77	17.70
106	6.68	7.84	2041	76.90	1304	8.66	3.14	23.10	1311	8.65	13.52	15.03
75	3.34	3.92	2766	71.02	794	5.27	4.75	28.98	797	5.26	16.32	11.03
53	1.54	1.81	3593	73.43	449	2.98	4.46	26.57	451	2.97	16.72	6.39
37	0.64	0.75	4380	68.07	317	2.11	4.17	31.93	318	2.10	13.02	3.51
25	0.230	0.27	4179	60.93	155	1.03	3.97	39.07	156	1.03	10.13	1.34
-25	0.597	0.70	4112	40.03	1888	12.53	1.95	59.97	1889	12.47	3.25	5.20
Total	85.20	100	937.7	67.72	15067	100	2.53	32.28	15152	100	7.79	100

Table 79: Metallurgical balance of pilot Knelson concentrator (Test 7)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.0004	10.85	7601	68.65	0.66	7.85	1.89	31.35	0.66	7.86	6.0	4.80
425	0.0005	13.91	7918	49.10	0.89	10.58	4.25	50.90	0.89	10.58	8.4	8.95
300	0.0005	16.39	8449	51.70	1.29	15.30	3.34	48.30	1.29	15.30	6.9	10.69
212	0.0006	17.97	8891	41.61	1.52	18.08	4.89	58.39	1.52	18.08	8.4	15.32
150	0.0006	17.77	10738	43.08	1.32	15.71	6.32	56.92	1.32	15.71	11.1	17.68
106	0.0003	9.52	13798	36.52	0.73	8.65	10.40	63.48	0.73	8.65	16.4	14.35
75	0.0002	4.99	20368	39.68	0.44	5.26	11.59	60.32	0.44	5.26	19.2	10.23
53	0.0002	4.75	30284	60.82	0.25	2.98	12.28	39.18	0.25	2.98	31.3	9.44
37	0.0000	1.43	41861	55.95	0.18	2.10	8.86	44.05	0.18	2.10	20.1	4.27
25	0.0000	0.70	35709	60.83	0.09	1.03	6.17	39.17	0.09	1.03	15.8	1.64
-25	0.0001	1.72	14322	37.52	1.05	12.47	1.30	62.48	1.05	12.46	2.1	2.63
Total	0.0033	100	11680	46.62	8.41	100	5.27	53.38	8.41	100	9.9	100

Table 80: Metallurgical balance of laboratory Knelson concentrator (Test 8)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(μm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.50	12.34	123	56.67	1135	7.87	0.79	43.33	1144	7.89	1.81	1.92
425	11.50	14.94	502	74.04	1498	10.38	1.35	25.96	1509	10.41	5.16	7.21
300	14.70	19.09	833	82.78	2216	15.36	1.15	17.22	2230	15.38	6.63	13.70
212	15.50	20.13	793	65.89	2639	18.29	2.41	34.11	2654	18.30	7.02	17.26
150	13.60	17.66	1081	75.47	2320	16.08	2.06	24.53	2334	16.09	8.35	18.04
106	6.50	8.44	1485	73.57	1247	8.64	2.78	26.43	1253	8.64	10.46	12.14
75	3.33	4.32	2472	72.79	745	5.16	4.13	27.21	748	5.16	15.11	10.47
53	1.42	1.84	4069	76.12	417	2.89	4.34	23.88	418	2.88	18.11	7.01
37	0.74	0.95	4781	73.98	301	2.08	4.11	26.02	301	2.08	15.76	4.40
25	0.50	0.65	3940	77.73	148	1.03	3.83	22.27	148	1.02	17.14	2.36
-25	0.39	0.50	5654	36.61	1762	12.21	2.14	63.39	1762	12.15	3.37	5.50
Total	77.00	100	1006	71.74	14426	100	2.12	28.26	14503	100	7.45	100

Table 81: Metallurgical balance of pilot Knelson concentrator (Test 8)

Size	CONCENTRATE				TAILS				FEED			
(μm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00037	11.05	7513	81.94	0.61	7.89	1.02	18.06	0.61	7.89	5.7	4.32
425	0.00048	14.25	7671	54.84	0.80	10.40	3.82	45.16	0.80	10.41	8.5	8.50
300	0.00056	16.66	8927	43.76	1.18	15.38	5.49	56.24	1.18	15.38	9.8	14.49
212	0.00064	18.93	7860	43.70	1.40	18.30	4.63	56.30	1.40	18.30	8.2	14.52
150	0.00061	17.94	9783	43.33	1.23	16.09	6.30	56.67	1.23	16.09	11.1	17.26
106	0.00030	8.83	15036	46.86	0.66	8.64	7.70	53.14	0.66	8.64	14.5	12.08
75	0.00015	4.38	22430	43.32	0.40	5.16	11.00	56.68	0.40	5.16	19.4	9.66
53	0.00014	4.10	32338	59.57	0.22	2.88	13.79	40.43	0.22	2.88	34.1	9.49
37	0.00005	1.37	43160	51.82	0.16	2.08	11.66	48.18	0.16	2.08	24.2	4.85
25	0.00002	0.68	36995	44.77	0.08	1.02	13.33	55.23	0.08	1.02	24.1	2.38
-25	0.00006	1.82	12875	40.80	0.93	12.15	1.24	59.20	0.93	12.14	2.1	2.45
Total	0.00339	100	11363	48.44	7.67	100	5.34	51.56	7.67	100	10.4	100

Table 82: Metallurgical balance of laboratory Knelson concentrator (Test 9)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(μm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.04	10.22	416	26.50	1199	7.86	8.69	73.50	1208	7.91	11.74	6.74
425	12.45	14.08	890	37.66	1686	11.05	10.88	62.34	1699	11.12	17.33	14.00
300	16.88	19.09	969	76.47	2368	15.52	2.12	23.53	2385	15.62	8.96	10.17
212	18.47	20.89	1258	77.89	2756	18.06	2.39	22.11	2774	18.17	10.75	14.18
150	16.32	18.46	1548	82.55	2575	16.87	2.07	17.45	2592	16.97	11.81	14.55
106	7.90	8.93	2498	75.22	1509	9.89	4.31	24.78	1517	9.93	17.30	12.47
75	4.09	4.63	4630	85.09	624	4.09	5.32	14.91	628	4.11	35.45	10.58
53	1.71	1.93	8319	91.58	480	3.14	2.73	8.42	481	3.15	32.27	7.39
37	0.96	1.09	8479	79.40	329	2.16	6.42	20.60	330	2.16	31.05	4.87
25	0.31	0.35	8362	72.64	151	0.99	6.40	27.36	152	0.99	23.34	1.68
-25	0.30	0.34	8742	37.14	1585	10.38	2.81	62.86	1585	10.38	4.47	3.37
Total	88.43	100	1650	69.38	15262	100	4.22	30.62	15271	100	13.77	100

Table 83: Metallurgical balance of pilot Knelson concentrator (Test 9)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00041	12.29	19511	72.54	0.98	7.87	3.11	27.46	0.98	7.87	11.3	5.14
425	0.00051	15.24	18718	51.58	1.37	11.07	6.53	48.42	1.38	11.07	13.5	8.60
300	0.00055	16.48	19644	45.04	1.93	15.54	6.86	54.96	1.93	15.54	12.5	11.17
212	0.00058	17.31	21499	39.88	2.24	18.07	8.37	60.12	2.25	18.07	13.9	14.51
150	0.00055	16.46	27064	42.19	2.10	16.88	9.75	57.81	2.10	16.88	16.9	16.42
106	0.00029	8.77	37462	40.81	1.23	9.88	13.01	59.19	1.23	9.88	22.0	12.52
75	0.00015	4.51	56466	35.79	0.51	4.09	30.17	64.21	0.51	4.09	47.0	11.08
53	0.00016	4.70	86287	54.13	0.39	3.14	29.55	45.87	0.39	3.14	64.4	11.65
37	0.00005	1.64	96350	44.53	0.27	2.15	24.66	55.47	0.27	2.15	44.4	5.51
25	0.00003	0.77	72041	47.01	0.12	0.99	16.95	52.99	0.12	0.99	32.0	1.82
-25	0.00006	1.83	20950	37.68	1.28	10.33	1.66	62.32	1.28	10.32	2.7	1.59
Total	0.00335	100	29066	45.19	12.42	100	9.51	54.81	12.42	100	17.3	100

Table 84: Metallurgical balance of laboratory Knelson concentrator (Test 10)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.82	8.54	478	76.24	1258	8.11	1.04	23.76	1267	8.11	4.36	3.29
425	11.34	10.98	876	82.84	1699	10.95	1.21	17.16	1710	10.95	7.01	7.14
300	16.23	15.71	765	77.59	2391	15.42	1.50	22.41	2408	15.42	6.65	9.53
212	20.20	19.56	994	73.33	2852	18.39	2.56	26.67	2872	18.40	9.53	16.29
150	18.82	18.22	1205	73.20	2493	16.08	3.33	26.80	2512	16.09	12.33	18.44
106	10.26	9.93	1641	81.66	1325	8.54	2.86	18.34	1335	8.55	15.44	12.28
75	7.16	6.93	2284	80.19	747	4.82	5.41	19.81	754	4.83	27.03	12.14
53	4.26	4.12	2686	79.65	382	2.46	7.66	20.35	386	2.47	37.24	8.55
37	3.04	2.94	2545	82.57	237	1.53	6.89	17.43	240	1.54	39.01	5.58
25	1.190	1.15	2200	79.14	97	0.62	7.15	20.86	98	0.63	33.86	1.97
-25	1.970	1.91	1641	40.21	2030	13.09	2.37	59.79	2032	13.01	3.96	4.79
Total	103.29	100	1235	75.93	15511	100	2.61	24.07	15614	100	10.76	100

Table 85: Metallurgical balance of pilot Knelson concentrator (Test 10)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.000370	10.91	13170	71.43	0.59	8.11	3.33	28.57	0.59	8.11	11.6	5.32
425	0.000502	14.80	13584	59.74	0.79	10.95	5.81	40.26	0.79	10.95	14.4	8.90
300	0.000595	17.56	13742	58.76	1.11	15.42	5.16	41.24	1.11	15.42	12.5	10.86
212	0.000652	19.25	14547	50.58	1.33	18.40	6.99	49.42	1.33	18.40	14.1	14.65
150	0.000581	17.15	20459	53.16	1.16	16.09	9.03	46.84	1.16	16.09	19.3	17.46
106	0.000283	8.35	30563	52.64	0.62	8.55	12.61	47.36	0.62	8.55	26.6	12.83
75	0.000143	4.21	43200	44.91	0.35	4.83	21.68	55.09	0.35	4.83	39.3	10.71
53	0.000140	4.14	60785	61.73	0.18	2.47	29.66	38.27	0.18	2.47	77.4	10.79
37	0.000047	1.40	58783	43.82	0.11	1.54	32.21	56.18	0.11	1.54	57.3	4.97
25	0.000024	0.71	50006	49.70	0.05	0.63	26.79	50.30	0.05	0.63	53.2	1.88
-25	0.000052	1.54	11541	28.72	0.94	13.01	1.59	71.28	0.94	13.01	2.2	1.64
Total	0.003390	100	20407	53.99	7.22	100	8.17	46.01	7.22	100	17.7	100

Table 86: Metallurgical balance of laboratory Knelson concentrator (Test 11)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.78	9.80	577	76.76	1157	7.40	1.33	23.24	1166	7.41	5.66	3.96
425	11.80	13.17	1153	88.40	1553	9.93	1.15	11.60	1565	9.94	9.84	9.25
300	16.29	18.18	1060	75.38	2319	14.83	2.43	24.62	2336	14.85	9.81	13.77
212	18.85	21.04	1071	81.73	2846	18.20	1.59	18.27	2865	18.21	8.62	14.84
150	17.35	19.36	1219	72.61	2545	16.27	3.13	27.39	2563	16.29	11.36	17.50
106	8.25	9.21	1882	75.26	1405	8.98	3.63	24.74	1413	8.98	14.60	12.40
75	4.23	4.72	3285	76.73	853	5.45	4.94	23.27	857	5.45	21.13	10.88
53	1.88	2.10	5018	79.22	475	3.04	5.21	20.78	477	3.03	24.96	7.15
37	0.68	0.76	6125	70.56	333	2.13	5.20	29.44	334	2.12	17.64	3.54
25	0.33	0.37	5200	71.09	163	1.04	4.30	28.91	163	1.04	14.86	1.45
-25	0.75	0.84	5456	47.02	1993	12.74	2.33	52.98	1994	12.67	4.39	5.26
Total	89.60	100	1408	75.78	15643	100	2.58	24.22	15733	100	10.58	100

Table 87: Metallurgical balance of pilot Knelson concentrator (Test 11)

Size (µm)	CONCENTRATE Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00035	10.38	11646	63.64	0.54	7.41	4.34	36.36	0.54	7.41	11.9	5.51
425	0.00046	13.60	11885	46.55	0.73	9.94	8.70	53.45	0.73	9.95	16.3	10.08
300	0.00056	16.58	11424	44.57	1.08	14.85	7.40	55.43	1.08	14.85	13.3	12.34
212	0.00065	19.24	11876	45.37	1.33	18.21	7.04	54.63	1.33	18.21	12.9	14.63
150	0.00063	18.55	15446	49.86	1.19	16.29	8.25	50.14	1.19	16.29	16.4	16.69
106	0.00032	9.34	23349	50.74	0.66	8.98	10.99	49.26	0.66	8.98	22.3	12.48
75	0.00016	4.65	34844	46.09	0.40	5.45	16.21	53.91	0.40	5.45	30.1	10.21
53	0.00015	4.31	50133	62.69	0.22	3.03	19.77	37.31	0.22	3.03	53.0	10.01
37	0.00005	1.35	61322	59.45	0.15	2.12	12.44	40.55	0.15	2.12	30.7	4.05
25	0.00002	0.69	48652	58.69	0.08	1.04	10.56	41.31	0.08	1.04	25.6	1.65
-25	0.00004	1.32	18782	30.58	0.92	12.67	2.06	69.42	0.92	12.67	3.0	2.35
Total	0.00340	100	17241	50.07	7.29	100	8.02	49.93	7.30	100	16.0	100

Table 88: Metallurgical balance of laboratory Knelson concentrator (Test 13)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.82	9.77	599	80.46	979	6.74	1.31	19.54	988	6.76	6.65	4.90
425	10.85	12.02	304	35.24	1295	8.92	4.69	64.76	1305	8.94	7.18	7.00
300	15.77	17.48	462	66.12	1963	13.52	1.90	33.88	1979	13.55	5.56	8.22
212	19.09	21.16	831	74.76	2551	17.57	2.10	25.24	2570	17.59	8.26	15.86
150	17.94	19.88	853	73.33	2378	16.38	2.34	26.67	2396	16.41	8.71	15.59
106	8.82	9.77	1330	65.07	1352	9.31	4.66	34.93	1361	9.32	13.25	13.47
75	4.57	5.06	2610	77.41	821	5.65	4.24	22.59	825	5.65	18.67	11.51
53	1.96	2.17	4308	75.57	468	3.23	5.83	24.43	470	3.22	23.76	8.35
37	1.07	1.19	5956	79.54	339	2.34	4.83	20.46	340	2.33	23.53	5.99
25	0.36	0.40	5429	71.86	176	1.21	4.36	28.14	176	1.20	15.46	2.03
-25	0.98	1.09	4408	45.74	2195	15.12	2.34	54.26	2196	15.03	4.31	7.07
Total	90.23	100	1017	68.58	14516	100	2.90	31.42	14606	100	9.16	100

Table 89: Metallurgical balance of pilot Knelson concentrator (Test 13)

Size (µm)	CONCENTRATE Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00027	9.75	8283	45.93	0.49	6.76	5.35	54.07	0.49	6.76	9.9	5.40
425	0.00036	12.87	9520	67.32	0.65	8.94	2.53	32.68	0.65	8.94	7.7	5.59
300	0.00046	16.60	9898	55.62	0.99	13.55	3.68	44.38	0.99	13.55	8.3	9.07
212	0.00055	19.72	10932	43.01	1.28	17.59	6.18	56.99	1.28	17.59	10.8	15.39
150	0.00052	18.66	15343	50.95	1.20	16.41	6.39	49.05	1.20	16.41	13.0	17.25
106	0.00025	9.08	24419	51.19	0.68	9.32	8.62	48.81	0.68	9.32	17.7	13.29
75	0.00012	4.47	36357	43.10	0.41	5.65	14.45	56.90	0.41	5.65	25.4	11.59
53	0.00012	4.40	47269	57.74	0.23	3.22	17.96	42.26	0.23	3.22	42.5	11.05
37	0.00005	1.66	51506	42.75	0.17	2.33	18.72	57.25	0.17	2.33	32.7	6.15
25	0.00002	0.85	38757	48.43	0.09	1.20	11.11	51.57	0.09	1.20	21.5	2.09
-25	0.00005	1.93	12579	23.77	1.10	15.03	1.97	76.23	1.10	15.03	2.6	3.14
Total	0.00277	100	16046	49.26	7.29	100	6.29	50.74	7.30	100	12.4	100

Table 90: Metallurgical balance of laboratory Knelson concentrator (Test 14)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.03	8.83	122	30.91	967	7.13	2.27	69.09	975	7.15	3.26	2.78
425	11.22	12.34	595	62.89	1296	9.56	3.04	37.11	1307	9.58	8.12	9.30
300	15.87	17.45	621	76.14	1851	13.66	1.67	23.86	1867	13.68	6.94	11.35
212	19	20.90	629	74.35	2342	17.28	1.76	25.65	2361	17.30	6.81	14.08
150	18.2	20.02	682	70.08	2180	16.09	2.43	29.92	2198	16.11	8.05	15.52
106	9.09	10.00	972	54.39	1255	9.26	5.90	45.61	1265	9.27	12.84	14.23
75	4.91	5.40	1754	67.64	777	5.73	5.30	32.36	782	5.73	16.28	11.15
53	2.17	2.39	2763	69.85	445	3.28	5.82	30.15	447	3.28	19.21	7.52
37	1.23	1.35	3687	74.38	322	2.38	4.85	25.62	323	2.37	18.86	5.34
25	0.39	0.43	3798	68.58	165	1.22	4.13	31.42	165	1.21	13.11	1.90
-25	0.82	0.90	4235	44.56	1953	14.41	2.21	55.44	1954	14.32	3.98	6.82
Total	90.93	100	823	65.55	13552	100	2.90	34.45	13643	100	8.36	100

Table 91: Metallurgical balance of pilot Knelson concentrator (Test 14)

Size (µm)	CONCENTRATE Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00033	9.36	4333	76.40	0.44	7.15	1.01	23.60	0.44	7.15	4.3	2.47
425	0.00042	11.79	5538	43.41	0.59	9.58	5.11	56.59	0.59	9.58	9.0	7.01
300	0.00052	14.76	5470	39.09	0.85	13.68	5.28	60.91	0.85	13.68	8.7	9.62
212	0.00064	17.90	10402	54.99	1.07	17.30	5.06	45.01	1.07	17.30	11.2	15.78
150	0.00066	18.55	10068	54.13	1.00	16.11	5.64	45.87	1.00	16.11	12.3	16.08
106	0.00036	10.03	14252	55.94	0.57	9.27	6.98	44.06	0.57	9.27	15.8	11.91
75	0.00020	5.50	28078	58.43	0.35	5.73	11.01	41.57	0.35	5.73	26.5	12.31
53	0.00021	5.82	30074	69.61	0.20	3.28	13.42	30.39	0.20	3.28	44.1	11.72
37	0.00008	2.25	43990	63.12	0.15	2.37	14.03	36.88	0.15	2.37	38.0	7.31
25	0.00004	1.23	28874	65.24	0.07	1.21	8.99	34.76	0.07	1.21	25.9	2.54
-25	0.00010	2.82	9028	36.55	0.89	14.32	1.78	63.45	0.89	14.31	2.8	3.25
Total	0.00356	100	11918	55.55	6.19	100	5.48	44.45	6.19	100	12.3	100

Table 92: Metallurgical balance of laboratory Knelson concentrator (Test 15)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.16	11.30	246	35.25	916	7.55	5.00	64.75	927	7.58	7.64	6.48
425	11.46	12.74	404	66.47	1275	10.52	1.83	33.53	1287	10.53	5.41	6.37
300	15.73	17.49	536	57.27	1829	15.08	3.44	42.73	1845	15.09	7.98	13.48
212	18.39	20.45	630	67.08	2170	17.89	2.62	32.92	2188	17.91	7.89	15.81
150	17.18	19.10	727	72.45	1923	15.86	2.47	27.55	1940	15.88	8.89	15.79
106	8.53	9.49	1126	74.43	1065	8.78	3.10	25.57	1073	8.78	12.03	11.82
75	4.56	5.07	1964	77.50	651	5.37	3.99	22.50	656	5.37	17.61	10.58
53	2.05	2.28	3086	76.58	371	3.05	5.22	23.42	373	3.05	22.17	7.56
37	1.12	1.25	4052	79.11	264	2.18	4.54	20.89	265	2.17	21.64	5.25
25	0.37	0.41	4329	76.70	132	1.09	3.64	23.30	132	1.08	15.58	1.89
-25	0.39	0.43	5684	40.52	1533	12.64	2.10	59.48	1534	12.55	3.53	4.96
Total	89.93	100	810	66.69	12130	100	3.00	33.31	12220	100	8.94	100

Table 93: Metallurgical balance of pilot Knelson concentrator (Test 15)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00030	11.14	12042	72.65	0.51	7.58	2.69	27.35	0.51	7.58	9.8	6.72
425	0.00038	13.95	7890	54.01	0.71	10.53	3.60	45.99	0.71	10.53	7.8	7.41
300	0.00045	16.55	2828	21.52	1.02	15.09	4.57	78.48	1.02	15.10	5.8	7.91
212	0.00051	18.60	2026	13.84	1.21	17.91	5.29	86.16	1.21	17.91	6.1	9.90
150	0.00048	17.79	15580	52.29	1.07	15.88	6.44	47.71	1.07	15.88	13.5	19.29
106	0.00024	8.92	11290	34.11	0.59	8.78	8.95	65.89	0.59	8.78	13.6	10.74
75	0.00012	4.40	29454	41.69	0.36	5.37	13.65	58.31	0.36	5.37	23.4	11.31
53	0.00011	4.17	72888	70.34	0.21	3.05	16.98	29.66	0.21	3.05	57.2	15.71
37	0.00004	1.51	52162	46.11	0.15	2.17	17.12	53.89	0.15	2.17	31.8	6.20
25	0.00002	0.79	39124	49.07	0.07	1.08	11.95	50.93	0.07	1.08	23.5	2.29
-25	0.00006	2.18	11344	35.79	0.85	12.55	1.43	64.21	0.85	12.55	2.2	2.52
Total	0.00272	100	12742	46.36	6.74	100	5.96	53.64	6.74	100	11.1	100

Table 94: Metallurgical balance of laboratory Knelson concentrator (Test 16)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.41	10.31	24	3.89	1212	6.66	4.70	96.11	1222	6.68	4.85	10.27
425	13.58	14.87	49	20.48	1943	10.67	1.33	79.52	1956	10.69	1.66	5.64
300	18.20	19.93	64	29.88	2645	14.53	1.03	70.12	2664	14.55	1.46	6.75
212	20.09	22.00	149	22.11	3869	21.24	2.73	77.89	3889	21.25	3.49	23.53
150	16.70	18.29	182	31.93	3035	16.67	2.13	68.07	3052	16.68	3.12	16.49
106	8.90	9.75	242	35.41	1761	9.67	2.23	64.59	1770	9.67	3.44	10.55
75	3.27	3.58	453	30.82	891	4.89	3.73	69.18	894	4.88	5.38	8.33
53	1.29	1.41	827	31.75	582	3.20	3.94	68.25	583	3.19	5.76	5.82
37	0.51	0.56	1284	27.53	289	1.58	6.03	72.47	289	1.58	8.31	4.16
25	0.19	0.21	2344	35.61	251	1.38	3.25	64.39	251	1.37	5.04	2.19
-25	0.20	0.22	2778	15.14	1733	9.52	1.77	84.86	1733	9.47	2.08	6.26
Total	91.30	100	158	25.07	18211	100	2.37	74.93	18302	100	3.15	100

Table 95: Metallurgical balance of pilot Knelson concentrator (Test 16)

Size	CONCENTRATE				TAILS				FEED			
(µm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00030	10.29	4569	94.43	0.43	6.68	0.19	5.57	0.43	6.68	3.38	3.67
425	0.00038	13.07	6563	91.44	0.69	10.69	0.34	8.56	0.69	10.69	3.98	6.92
300	0.00046	15.78	5957	87.02	0.94	14.55	0.44	12.98	0.94	14.55	3.37	7.96
212	0.00053	17.98	15701	88.65	1.37	21.25	0.77	11.35	1.37	21.25	6.80	23.48
150	0.00052	17.59	4462	68.22	1.08	16.67	1.00	31.78	1.08	16.67	3.13	8.48
106	0.00028	9.48	10008	78.52	0.62	9.67	1.22	21.48	0.63	9.67	5.67	8.91
75	0.00015	5.24	30142	89.85	0.32	4.88	1.66	10.15	0.32	4.88	16.32	12.95
53	0.00016	5.43	38188	94.16	0.21	3.19	1.83	5.84	0.21	3.19	31.31	16.23
37	0.00005	1.86	42924	90.95	0.10	1.58	2.29	9.05	0.10	1.58	25.26	6.49
25	0.00003	1.00	29628	84.56	0.09	1.37	1.79	15.44	0.09	1.37	11.62	2.59
-25	0.00007	2.30	10810	79.08	0.61	9.47	0.32	20.92	0.61	9.47	1.51	2.32
Total	0.00293	100	11819	87.16	6.46	100	0.79	12.84	6.46	100	6.15	100

Table 96: Metallurgical balance of laboratory Knelson concentrator (Test 16F)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson feed)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.84	10.96	260	69.69	662	7.34	1.68	30.31	672	7.37	5.46	3.05
425	11.82	13.16	689	80.85	838	9.29	2.30	19.15	850	9.33	11.84	8.37
300	15.66	17.44	518	55.50	1215	13.47	5.35	44.50	1231	13.50	11.87	12.14
212	17.96	20.00	773	85.92	1538	17.04	1.48	14.08	1556	17.07	10.39	13.43
150	16.72	18.62	1100	85.26	1426	15.79	2.23	14.74	1442	15.82	14.95	17.92
106	8.5	9.47	1412	79.95	815	9.03	3.69	20.05	824	9.04	18.22	12.47
75	4.74	5.28	2397	80.13	505	5.60	5.58	19.87	510	5.59	27.82	11.78
53	2.22	2.47	3873	86.13	295	3.27	4.70	13.87	297	3.26	33.62	8.30
37	1.31	1.46	4809	87.13	221	2.45	4.21	12.87	222	2.44	32.51	6.01
25	0.39	0.43	4430	79.59	115	1.28	3.82	20.41	116	1.27	18.65	1.79
-25	0.63	0.70	4400	48.76	1394	15.45	2.09	51.24	1395	15.30	4.08	4.73
Total	89.79	100	1045	77.98	9025	100	2.94	22.02	9115	100	13.20	100

Table 97: Metallurgical balance of laboratory Knelson concentrator (Test 5T1)

Size	CONCENTRATE				TAILS				FEED (Pilot Knelson tails-1)			
(µm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	6.66	7.42	449	71.28	787	5.11	1.53	28.72	794	5.12	5.28	2.89
425	11.23	12.51	401	57.51	1472	9.55	2.26	42.49	1483	9.57	5.28	5.39
300	16.14	17.97	584	53.44	2298	14.92	3.57	46.56	2315	14.94	7.61	12.14
212	19.62	21.85	716	72.18	2849	18.49	1.90	27.82	2868	18.51	6.78	13.40
150	18.45	20.55	911	73.14	2626	17.05	2.35	26.86	2645	17.07	8.69	15.83
106	9.06	10.09	1611	64.79	1508	9.79	5.26	35.21	1517	9.79	14.85	15.52
75	4.74	5.28	3018	79.07	928	6.02	4.08	20.93	933	6.02	19.40	12.46
53	2.01	2.24	5150	81.68	525	3.41	4.42	18.32	527	3.40	24.03	8.73
37	1.11	1.24	6577	80.04	366	2.38	4.97	19.96	367	2.37	24.82	6.28
25	0.40	0.44	6810	77.18	173	1.13	4.61	22.82	174	1.12	20.16	2.41
-25	0.38	0.43	7283	38.84	1872	12.15	2.34	61.16	1873	12.08	3.83	4.93
Total	89.80	100	1111	68.75	15406	100	2.94	31.25	15496	100	9.37	100

Table 98: Metallurgical balance of laboratory Knelson concentrator (Test 5T2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails-2) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	6.34	7.09	5	0.76	707	4.68	6.02	99.24	713	4.69	6.01	2.93
425	10.82	12.10	629	72.07	1319	8.73	2.00	27.93	1330	8.75	7.10	6.44
300	16.02	17.92	647	61.86	2108	13.95	3.03	38.14	2124	13.97	7.89	11.42
212	19.39	21.69	733	75.34	2706	17.90	1.72	24.66	2725	17.93	6.92	12.87
150	18.49	20.69	948	70.51	2562	16.95	2.86	29.49	2580	16.97	9.63	16.95
106	9.23	10.33	1595	73.60	1496	9.90	3.53	26.40	1505	9.90	13.29	13.64
75	4.84	5.41	2756	74.69	924	6.12	4.89	25.31	929	6.11	19.22	12.18
53	2.08	2.33	4711	78.52	527	3.48	5.09	21.48	529	3.48	23.60	8.51
37	1.12	1.25	6141	77.03	380	2.51	5.40	22.97	381	2.51	23.44	6.09
25	0.342	0.38	5310	72.17	190	1.26	3.68	27.83	191	1.25	13.20	1.72
-25	0.713	0.80	3878	26.03	2195	14.52	3.58	73.97	2195	14.44	4.84	7.25
Total	89.39	100	1099	67.02	15113	100	3.20	32.98	15202	100	9.64	100

Table 99: Metallurgical balance of laboratory Knelson concentrator (Test 5T3)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails-3) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	7.12	7.89	166	66.37	778	4.97	0.77	33.63	785	4.99	2.27	1.37
425	11.58	12.83	545	74.10	1422	9.08	1.55	25.90	1434	9.10	5.94	6.54
300	16.31	18.08	491	58.05	2258	14.42	2.56	41.95	2275	14.44	6.06	10.58
212	19.23	21.31	705	76.38	2852	18.21	1.47	23.62	2871	18.23	6.18	13.63
150	18.06	20.02	1012	64.43	2607	16.65	3.87	35.57	2625	16.66	10.81	21.78
106	8.95	9.92	1661	75.37	1490	9.52	3.26	24.63	1499	9.52	13.16	15.15
75	4.68	5.19	2889	78.68	916	5.85	4.00	21.32	921	5.84	18.66	13.20
53	2.02	2.24	1309	56.97	522	3.33	3.83	43.03	524	3.32	8.87	3.56
37	1.17	1.30	5777	81.48	370	2.36	4.15	18.52	371	2.36	22.33	6.37
25	0.365	0.40	5718	69.40	189	1.21	4.86	30.60	190	1.20	15.85	2.31
-25	0.746	0.83	3681	38.31	2256	14.41	1.96	61.69	2257	14.33	3.18	5.51
Total	90.23	100	997	69.08	15662	100	2.57	30.92	15752	100	8.27	100

Table 100: Metallurgical balance of laboratory Knelson concentrator (Test 5T4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	6.26	6.84	397	64.44	1173	6.66	1.17	35.56	1180	6.66	3.27	2.59
425	12.61	13.78	344	67.31	1880	10.67	1.12	32.69	1893	10.68	3.40	4.32
300	17.81	19.46	567	42.12	2560	14.53	5.42	57.88	2578	14.55	9.30	16.09
212	20.34	22.23	749	64.20	3744	21.24	2.27	35.80	3765	21.25	6.31	15.93
150	17.97	19.64	1053	65.11	2938	16.67	3.45	34.89	2956	16.68	9.83	19.50
106	8.35	9.12	1763	75.19	1704	9.67	2.85	24.81	1713	9.67	11.43	13.14
75	4.23	4.62	3147	74.27	862	4.89	5.35	25.73	866	4.89	20.69	12.03
53	1.85	2.02	4822	77.19	563	3.20	4.68	22.81	565	3.19	20.45	7.76
37	1.07	1.17	2420	71.75	279	1.58	3.65	28.25	280	1.58	12.87	2.42
25	0.383	0.42	5762	74.10	243	1.38	3.18	25.90	243	1.37	12.26	2.00
-25	0.64	0.70	4543	46.30	1678	9.52	2.01	53.70	1678	9.47	3.74	4.21
Total	91.51	100	1046	64.25	17625	100	3.02	35.75	17717	100	8.41	100

Table 101: Metallurgical balance of pilot Knelson concentrator (Test 5)

Size (µm)	CONCENTRATE Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	FEED Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00021	5.74	42176	81.05	1.17	5.52	1.74	18.95	1.17	5.52	9.2	3.37
425	0.00036	10.10	43471	69.08	2.05	9.65	3.45	30.92	2.05	9.65	11.2	7.17
300	0.00051	14.06	43592	63.94	3.07	14.48	4.05	36.06	3.07	14.48	11.2	10.81
212	0.00066	18.33	41226	59.13	4.08	19.23	4.60	40.87	4.08	19.23	11.3	14.41
150	0.00076	21.13	45680	59.10	3.56	16.79	6.74	40.90	3.56	16.79	16.5	18.42
106	0.00045	12.60	57691	57.84	2.05	9.68	9.28	42.16	2.05	9.68	22.0	14.17
75	0.00024	6.78	72635	49.94	1.19	5.60	14.94	50.06	1.19	5.60	29.8	11.12
53	0.00023	6.40	107790	72.16	0.70	3.32	13.61	27.84	0.70	3.32	48.9	10.79
37	0.00007	2.00	140111	57.88	0.45	2.13	16.23	42.12	0.45	2.13	38.5	5.45
25	0.00003	0.94	115269	57.41	0.27	1.25	10.82	42.59	0.27	1.25	25.4	2.12
-25	0.00007	1.94	48117	48.74	2.62	12.36	1.34	51.26	2.62	12.35	2.6	2.16
Total	0.00360	100	54047	60.97	21.21	100	5.87	39.03	21.21	100	15.0	100

Table 102: Metallurgical balance of laboratory Knelson concentrator (Test 5F1)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-1) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.63	9.57	720	78.10	611	6.97	2.85	21.90	620	6.99	12.83	5.62
425	11.03	12.23	710	84.03	831	9.48	1.79	15.97	842	9.51	11.06	6.59
300	15.45	17.12	799	89.17	1230	14.02	1.22	10.83	1245	14.05	11.12	9.80
212	18.58	20.59	827	91.66	1128	12.86	1.24	8.34	1147	12.94	14.62	11.86
150	18.02	19.97	1099	79.89	1529	17.43	3.26	20.11	1547	17.45	16.02	17.53
106	9.23	10.23	1675	75.87	900	10.26	5.46	24.13	910	10.26	22.40	14.41
75	4.95	5.49	3217	89.28	569	6.49	3.36	10.72	574	6.48	31.07	12.61
53	2.15	2.38	5284	86.50	330	3.77	5.37	13.50	332	3.75	39.51	9.29
37	1.19	1.32	6648	88.60	238	2.72	4.27	11.40	240	2.70	37.27	6.31
25	0.402	0.45	5721	82.19	120	1.37	4.14	17.81	121	1.36	23.17	1.98
-25	0.591	0.66	4337	45.21	1284	14.64	2.42	54.79	1284	14.49	4.41	4.01
Total	90.22	100	1298	82.79	8772	100	2.77	17.21	8862	100	15.96	100

Table 103: Metallurgical balance of laboratory Knelson concentrator (Test 5F2)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-2) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.89	12.08	334.2	83.95	703	7.74	0.99	16.05	714	7.78	6.07	3.25
425	12.35	13.70	784.6	84.14	900	9.91	2.03	15.86	912	9.95	12.62	8.64
300	15.67	17.38	961.3	80.36	1274	14.02	2.89	19.64	1289	14.06	14.54	14.06
212	17.88	19.83	893.2	87.44	1604	17.66	1.43	12.56	1622	17.68	11.26	13.70
150	16.72	18.55	1144	88.22	1477	16.26	1.73	11.78	1493	16.28	14.52	16.26
106	8.46	9.38	1795	85.11	846	9.31	3.14	14.89	854	9.32	20.89	13.39
75	4.46	4.95	3006	87.82	531	5.85	3.50	12.18	536	5.84	28.49	11.45
53	1.95	2.16	4812	87.15	311	3.42	4.45	12.85	313	3.41	34.42	8.08
37	1.08	1.20	5934	87.96	227	2.50	3.86	12.04	228	2.49	31.92	5.47
25	0.296	0.33	5921	81.05	117	1.29	3.50	18.95	117	1.28	18.43	1.62
-25	0.401	0.44	6145	45.42	1093	12.03	2.71	54.58	1093	11.92	4.96	4.07
Total	90.16	100	1243	84.10	9082	100	2.33	15.90	9172	100	14.53	100

Table 104: Metallurgical balance of laboratory Knelson concentrator (Test 5F3)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot knelson feed-3) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.2	11.36	536	82.38	769	8.05	1.52	17.62	780	8.08	8.51	5.44
425	12.26	13.65	761	87.18	1010	10.56	1.36	12.82	1022	10.59	10.48	8.78
300	15.88	17.68	646	78.22	1393	14.57	2.05	21.78	1409	14.60	9.31	10.75
212	18.08	20.13	868	86.30	1638	17.14	1.52	13.70	1656	17.17	10.98	14.91
150	16.73	18.63	1024	80.37	1418	14.83	2.95	19.63	1435	14.87	14.85	17.47
106	8.27	9.21	1541	85.17	804	8.41	2.76	14.83	812	8.42	18.42	12.26
75	4.41	4.91	2718	84.02	502	5.25	4.54	15.98	507	5.25	28.16	11.69
53	1.97	2.19	4037	88.15	295	3.09	3.62	11.85	297	3.08	30.35	7.39
37	1.1	1.22	5202	88.46	220	2.30	3.39	11.54	221	2.29	29.22	5.30
25	0.316	0.35	3880	75.38	116	1.21	3.45	24.62	116	1.21	13.98	1.33
-25	0.608	0.68	4487	48.00	1394	14.58	2.12	52.00	1395	14.45	4.08	4.66
Total	89.82	100	1116	82.18	9560	100	2.27	17.82	9650	100	12.64	100

Table 105: Metallurgical balance of laboratory Knelson concentrator (Test 5F4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.42	11.81	870	90.35	712	8.11	1.36	9.65	722	8.14	13.89	8.69
425	11.97	13.57	701	76.17	915	10.42	2.87	23.83	927	10.45	11.89	9.54
300	15.83	17.94	763	85.24	1275	14.53	1.64	14.76	1291	14.56	10.97	12.27
212	17.95	20.35	707	80.14	1520	17.32	2.07	19.86	1538	17.35	10.30	13.72
150	16.3	18.48	915	78.10	1311	14.93	3.19	21.90	1327	14.97	14.38	16.54
106	8.00	9.07	1408	79.66	734	8.36	3.92	20.34	742	8.36	19.06	12.25
75	4.23	4.80	2288	83.45	455	5.18	4.22	16.55	459	5.18	25.26	10.05
53	1.80	2.04	3529	86.28	264	3.01	3.82	13.72	266	3.00	27.65	6.38
37	0.91	1.03	4899	87.48	196	2.23	3.26	12.52	197	2.22	25.92	4.41
25	0.29	0.33	5340	82.43	105	1.20	3.10	17.57	106	1.19	17.60	1.61
-25	0.52	0.59	3986	39.29	1292	14.71	2.47	60.71	1292	14.57	4.07	4.55
Total	88.22	100	1048	80.10	8779	100	2.62	19.90	8867	100	13.02	100

Table 106: Metallurgical balance of laboratory Knelson concentrator (Test 12T1)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson tails-1) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.85	9.85	449	57.15	1201	8.29	2.48	42.85	1210	8.30	5.74	5.14
425	11.93	13.27	401	69.40	1660	11.47	1.27	30.60	1672	11.48	4.12	5.10
300	16.86	18.76	584	63.06	2243	15.49	2.57	36.94	2260	15.51	6.90	11.54
212	19.15	21.31	716	77.69	2491	17.20	1.58	22.31	2510	17.22	7.03	13.04
150	16.82	18.71	911	71.11	2102	14.52	2.96	28.89	2119	14.54	10.16	15.93
106	7.95	8.84	1611	75.71	1164	8.04	3.53	24.29	1172	8.04	14.44	12.51
75	4.24	4.72	3018	76.00	729	5.04	5.54	24.00	734	5.03	22.95	12.45
53	1.93	2.15	5150	81.54	434	2.99	5.19	18.46	436	2.99	27.98	9.01
37	1.20	1.34	6577	85.96	330	2.28	3.91	14.04	331	2.27	27.74	6.79
25	0.43	0.48	6810	80.87	185	1.28	3.76	19.13	185	1.27	19.61	2.69
-25	0.52	0.58	7283	48.51	1944	13.42	2.08	51.49	1944	13.34	4.04	5.81
Total	89.89	100	1088	72.32	14483	100	2.59	27.68	14573	100	9.28	100

Table 107: Metallurgical balance of laboratory Knelson concentrator (Test 12T2)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails-2) Weight (g)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	9.73	10.96	5	1.24	663	4.68	6.02	98.76	672	4.72	6.01	2.93
425	11.54	13.00	629	74.59	1236	8.73	2.00	25.41	1248	8.75	7.80	7.05
300	16.03	18.06	647	63.40	1975	13.95	3.03	36.60	1991	13.97	8.21	11.85
212	18.35	20.68	733	75.52	2536	17.90	1.72	24.48	2554	17.92	6.97	12.91
150	16.60	18.71	948	69.61	2401	16.95	2.86	30.39	2418	16.96	9.35	16.37
106	8.02	9.04	1595	72.11	1402	9.90	3.53	27.89	1410	9.89	12.58	12.85
75	4.26	4.80	2756	73.48	866	6.12	4.89	26.52	871	6.11	18.35	11.57
53	1.96	2.21	4711	78.61	494	3.48	5.09	21.39	495	3.48	23.70	8.51
37	1.21	1.36	6141	79.45	356	2.51	5.40	20.55	357	2.51	26.18	6.78
25	0.43	0.48	5310	77.63	178	1.26	3.68	22.37	179	1.25	16.41	2.13
-25	0.62	0.69	3878	24.49	2057	14.52	3.58	75.51	2058	14.44	4.74	7.07
Total	88.75	100	1045	67.17	14164	100	3.20	32.83	14253	100	9.68	100

Table 108: Metallurgical balance of laboratory Knelson concentrator (Test 12T3)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails-3) Weight (g)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	7.12	7.89	166	68.24	715	4.97	0.77	31.76	722	4.99	2.40	1.37
425	11.58	12.83	545	75.69	1306	9.08	1.55	24.31	1318	9.10	6.32	6.56
300	16.31	18.08	491	60.11	2074	14.42	2.56	39.89	2091	14.44	6.37	10.49
212	19.23	21.31	705	77.88	2620	18.21	1.47	22.12	2639	18.23	6.60	13.71
150	18.06	20.02	1012	66.36	2395	16.65	3.87	33.64	2413	16.67	11.42	21.70
106	8.95	9.92	1661	76.91	1369	9.52	3.26	23.09	1378	9.52	14.03	15.23
75	4.68	5.19	2889	80.07	841	5.85	4.00	19.93	846	5.84	19.96	13.30
53	2.02	2.24	1309	59.04	479	3.33	3.83	40.96	481	3.32	9.31	3.53
37	1.17	1.30	5777	82.72	340	2.36	4.15	17.28	341	2.36	23.94	6.44
25	0.37	0.40	5718	71.17	174	1.21	4.86	28.83	174	1.20	16.82	2.31
-25	0.75	0.83	3681	40.34	2073	14.41	1.96	59.66	2073	14.32	3.28	5.36
Total	90.23	100	997	70.86	14386	100	2.57	29.14	14476	100	8.77	100

Table 109: Metallurgical balance of laboratory Knelson concentrator (Test 12T4)

Size (µm)	CONCENTRATE Weight (g)	CONCENTRATE % Weight	CONCENTRATE Grade (g/t)	CONCENTRATE Rec. (%)	TAILS Weight (g)	TAILS % Weight	TAILS Grade (g/t)	TAILS Rec. (%)	FEED (Pilot Knelson tails-4) Weight (g)	FEED % Weight	FEED Grade (g/t)	FEED Dist'n (%)
600	6.26	6.84	397	68.16	993	6.66	1.17	31.84	999	6.66	3.65	2.59
425	12.61	13.78	344	70.86	1592	10.67	1.12	29.14	1604	10.69	3.81	4.34
300	17.81	19.46	567	46.23	2167	14.53	5.42	53.77	2185	14.56	10.00	15.51
212	20.34	22.23	749	67.93	3170	21.24	2.27	32.07	3190	21.25	7.03	15.93
150	17.97	19.64	1053	68.80	2487	16.67	3.45	31.20	2505	16.69	10.98	19.53
106	8.35	9.12	1763	78.16	1443	9.67	2.85	21.84	1451	9.67	12.98	13.37
75	4.23	4.62	3147	77.32	730	4.89	5.35	22.68	734	4.89	23.46	12.23
53	1.85	2.02	4822	79.99	477	3.20	4.68	20.01	479	3.19	23.30	7.92
37	1.07	1.17	2420	75.00	236	1.58	3.65	25.00	237	1.58	14.54	2.45
25	0.38	0.42	5762	77.17	205	1.38	3.18	22.83	206	1.37	13.90	2.03
-25	0.64	0.70	4543	50.46	1420	9.52	2.01	49.54	1421	9.46	4.06	4.09
Total	91.51	100	1046	67.98	14919	100	3.02	32.02	15011	100	9.38	100

Table 110: Metallurgical balance of pilot Knelson concentrator (Test 12)

	CONCENTRATE				TAILS				FEED			
Size (μm)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Rec. (%)	Weight (tons)	% Weight	Grade (g/t)	Dist'n (%)
600	0.00027	9.30	33655	76.78	1.44	6.05	1.92	23.22	1.44	6.05	8.3	3.90
425	0.00035	12.05	35930	58.36	2.37	9.97	3.81	41.64	2.37	9.97	9.1	7.09
300	0.00044	15.16	34350	49.14	3.46	14.58	4.55	50.86	3.46	14.58	8.9	10.13
212	0.00054	18.62	34860	45.06	4.52	19.02	5.12	54.94	4.52	19.02	9.3	13.76
150	0.00056	19.13	47465	48.05	3.89	16.37	7.38	51.95	3.89	16.37	14.2	18.06
106	0.00030	10.18	71986	48.47	2.23	9.38	10.21	51.53	2.23	9.38	19.8	14.44
75	0.00016	5.33	103983	43.54	1.29	5.44	16.25	56.46	1.29	5.44	28.8	12.15
53	0.00016	5.46	123957	63.06	0.77	3.25	15.02	36.94	0.77	3.25	40.6	10.26
37	0.00006	1.98	129328	44.53	0.50	2.11	18.58	55.47	0.50	2.11	33.5	5.49
25	0.00003	1.02	83299	39.71	0.30	1.28	12.45	60.29	0.30	1.28	20.6	2.05
-25	0.00005	1.76	69913	44.11	2.98	12.56	1.53	55.89	2.98	12.56	2.7	2.67
Total	0.00292	100	52523	50.18	23.76	100	6.41	49.82	23.76	100	12.9	100

Table 111: Metallurgical balance of laboratory Knelson concentrator (Test 12F1)

	CONCENTRATE				TAILS				FEED (Pilot Knelson feed-1)			
Size (μm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.65	11.90	746	69.26	1071	7.10	3.29	30.74	1082	7.13	10.60	4.83
425	12.09	13.51	1288	54.96	1392	9.22	9.17	45.04	1404	9.25	20.18	11.94
300	15.91	17.78	1495	86.76	2028	13.44	1.79	13.24	2044	13.46	13.41	11.56
212	18.06	20.18	1317	76.58	2607	17.28	2.79	23.42	2625	17.29	11.83	13.09
150	16.45	18.38	1779	69.50	2387	15.82	5.38	30.50	2403	15.83	17.52	17.75
106	8.05	9.00	2782	84.55	1356	8.98	3.02	15.45	1364	8.98	19.43	11.17
75	4.22	4.72	4968	82.30	849	5.63	5.31	17.70	853	5.62	29.85	10.74
53	1.89	2.11	7668	83.86	503	3.34	5.54	16.14	505	3.33	34.20	7.29
37	1.11	1.24	9410	84.89	380	2.51	4.90	15.11	381	2.51	32.33	5.19
25	0.39	0.44	8534	81.69	209	1.39	3.59	18.31	210	1.38	19.57	1.73
-25	0.67	0.75	7092	42.62	2309	15.30	2.77	57.38	2310	15.22	4.83	4.70
Total	89.49	100	1975	74.52	15092	100	4.00	25.48	15181	100	15.62	100

Table 112: Metallurgical balance of laboratory Knelson concentrator (Test 12F2)

	CONCENTRATE				TAILS				FEED (Pilot Knelson feed-2)			
Size (μm)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Rec. (%)	Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	9.05	10.13	803	86.72	1266	7.27	0.88	13.28	1275	7.29	6.58	3.67
425	11.73	13.13	771	53.41	1689	9.71	4.67	46.59	1701	9.72	9.96	7.41
300	15.82	17.71	1343	81.76	2406	13.83	1.97	18.24	2422	13.85	10.73	11.37
212	18.35	20.55	1423	81.40	2998	17.23	1.99	18.60	3016	17.24	10.64	14.04
150	17.23	19.29	1745	82.61	2729	15.68	2.32	17.39	2746	15.70	13.26	15.93
106	8.64	9.67	2742	80.43	1546	8.88	3.73	19.57	1554	8.88	18.95	12.89
75	4.61	5.16	4907	80.51	963	5.53	5.69	19.49	967	5.53	29.05	12.30
53	2.01	2.25	8436	84.02	576	3.31	5.60	15.98	578	3.30	34.93	8.83
37	1.1	1.23	10664	83.62	444	2.55	5.18	16.38	445	2.54	31.54	6.14
25	0.3	0.34	11743	78.61	243	1.40	3.94	21.39	244	1.39	18.40	1.96
-25	0.472	0.53	12329	46.60	2546	14.63	2.62	53.40	2546	14.55	4.91	5.46
Total	89.31	100	1994	77.93	17405	100	2.90	22.07	17494	100	13.06	100

Table 113: Metallurgical balance of labortory Knelson concentrator (Test 12F3)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-3) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	8.75	9.77	554	85.49	784	7.39	1.05	14.51	792	7.41	7.16	3.86
425	11.91	13.30	761	61.27	1023	9.65	5.60	38.73	1035	9.68	14.29	10.07
300	16	17.86	884	79.79	1444	13.62	2.48	20.21	1460	13.65	12.14	12.07
212	18.16	20.28	828	81.49	1817	17.13	1.88	18.51	1835	17.16	10.06	12.57
150	17.05	19.04	1136	77.44	1654	15.60	3.41	22.56	1671	15.62	14.96	17.03
106	8.73	9.75	1837	81.90	945	8.92	3.75	18.10	954	8.92	20.53	13.34
75	4.58	5.11	2975	84.87	590	5.56	4.12	15.13	594	5.56	27.02	10.93
53	2.00	2.23	4900	86.04	349	3.29	4.56	13.96	351	3.28	32.48	7.76
37	1.27	1.42	5819	85.85	266	2.51	4.58	14.15	267	2.50	32.22	5.86
25	0.43	0.48	5460	82.19	145	1.36	3.50	17.81	145	1.36	19.59	1.94
-25	0.69	0.77	5008	51.10	1588	14.98	2.07	48.90	1589	14.86	4.23	4.58
Total	89.56	100	1285	78.37	10603	100	3.00	21.63	10693	100	13.73	100

Table 114: Metallurgical balance of laboratory Knelson concentrator (Test 12F4)

Size (µm)	CONCENTRATE Weight (g)	% Weight	Grade (g/t)	Rec. (%)	TAILS Weight (g)	% Weight	Grade (g/t)	Rec. (%)	FEED (Pilot Knelson feed-4) Weight (g)	% Weight	Grade (g/t)	Dist'n (%)
600	10.63	11.92	427	73.02	665	7.73	2.52	26.98	675	7.78	9.19	5.11
425	11.93	13.38	507	74.49	866	10.08	2.39	25.51	878	10.11	9.24	6.67
300	15.56	17.45	747	85.41	1211	14.08	1.64	14.59	1226	14.12	11.10	11.19
212	17.52	19.65	770	85.28	1493	17.37	1.56	14.72	1510	17.39	10.47	13.01
150	16.42	18.41	1173	85.38	1325	15.41	2.49	14.62	1341	15.44	16.82	18.55
106	8.36	9.38	2657	89.44	741	8.62	3.54	10.56	749	8.63	33.14	20.42
75	4.39	4.92	981	65.21	458	5.33	5.02	34.79	462	5.32	14.29	5.43
53	2.01	2.25	4044	84.07	275	3.20	5.60	15.93	277	3.19	34.89	7.95
37	1.23	1.38	4848	87.76	214	2.49	3.89	12.24	215	2.48	31.60	5.59
25	0.378	0.42	4027	79.76	119	1.39	3.24	20.24	120	1.38	15.96	1.57
-25	0.744	0.83	3904	52.93	1230	14.31	2.10	47.07	1231	14.17	4.46	4.51
Total	89.17	100	1121	82.22	8597	100	2.52	17.78	8686	100	14.00	100

Appendix 4 Images of tungsten particles

Figure 56: Tungsten particles (-850 + 600 µm)

Figure 57: Tungsten particles (-300 + 212 µm)

Figure 58: Tungsten particles (-212+ 150 µm)