Maximizing Gravity Recovery through the Application of Multiple Gravity Devices

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ABSTRACT

Recovery via gravity is one of the oldest mineral processing methods available. Unfortunately, the use of gravity techniques for gold recovery has been in decline for the past century as more effective chemical processes such as flotation and leach/CIP have been developed. Recently, with the push towards more sustainable environmental outcomes, the benefits of gravity separation have become more apparent. While gravity as a unit process is not usually capable of achieving as high a recovery as flotation or whole ore cyanidation, a combination of gravity devices alone or in conjunction with these processes can offer significant advantages to the operator.

This paper reviews the range of gravity devices available, their application and the results that can be achieved by maximizing gravity through the use of a combination of gravity recovery devices. Three case studies are provided.

INTRODUCTION

Many of the methods utilized today for gold recovery are based on practices that have been known or established for many centuries. The earliest known recovery method of gold, dating back thousands of years is gravity concentration. During the gold rush era, beginning in first half of the 19^{th} century, gravity concentration equipment was developed to treat a wider variety of ore types on an increasing scale. During this period of development, gravity concentration and amalgamation were used in crushing circuits to recovery gold at the earliest possible stage in the flowsheet; a principle in flowsheet design that is still valid today [1].

Despite continuing improvements to gravity recovery methods, these methods were still limited by their inability to recover fine gold or gold associated with sulphides. These limitations led to the development of alternative approaches, such as chlorination and cyanidation, followed by flotation of sulphide associated gold in the early 20^{th} century. With the emergence and acceptance of new technology, and the reliance on finer grinds for gold liberation, the use of gravity separation in gold flowsheets gradually declined throughout most of the 20^{th} century.

In 1934, the U.S. government set the official gold selling price at $35 US per ounce. This limitation hurt the industry, as rising inflation costs resulted in reduced profitability. Relief for the gold industry came in the early 1970s, when the US dollar was devalued, which led to dramatic increases in the gold price during the mid to latter portion of the decade.

As the economic climate for the gold industry improved, interest in the development of precious metals projects, both small and large scale continued to grow. Technological development also boomed throughout the 1980s, with new processes accepted into industry such as CIP and CIL processing, heap leaching of low grade ores, pressure oxidation of sulphides, and intensive cyanidation.

The 1980s also saw a re-emergence in the use of gravity separation technology. Much of this renewed interest could be attributed to the development of centrifugal concentrators aimed at the gravity recovery of previously unrecoverable fine free gold. Gravity recovery addresses the problem of coarse gold that cannot be completely leached in cyanidation. This paper reviews the range of gravity devices available, their application and the results that can be achieved by maximizing gravity through the use of a combination of gravity recovery devices. Three case studies are provided.

TYPES OF GRAVITY SEPARATION EQUIPMENT

Gravity separation is an environmentally friendly process, which utilizes simple equipment with few moving parts. Throughout the history of mineral processing, many different types of gravity separation devices have been utilized. Each of these devices takes advantage of density differences between valuable and gangue minerals. In the following sections, the operation theory for many of the more prominent gravity separation devices will be discussed, followed by advantages and limitations for each.

Shaking Table

Over 100 years ago, the Wilfley table was introduced as the first version of the shaking table, and is still utilized in gravity flowsheets today. Other commercial units available include the Holman and Deister tables. Due to their low capacities (less than 2 tph), shaking tables are typically used as cleaners for final upgrading of gravity concentrate produced from centrifugal concentrators, jigs and spirals. A wide range of gold recoveries can be expected, which are influenced by operator skill, table set-up, ore mineralogy, and degree of liberation.

Theory of Operation

Figure 1 illustrates a typical shaking table. Feed slurry is fed at the top corner of the table, and segregates according to differences in particle density and size. Feed density is typically maintained below 40% solids by weight to insure optimum performance.

Segregation results from the shaking action of the table, which oscillates backwards and forwards at right angles to the slope of the table. Riffles on the table surface provide retention time, and hold back material that is closest to the table surface. The combined effect of the table oscillation and riffles cause the fine heavies to ride the surface of the table, and thus report to the uppermost section of the table edge as concentrate. Lower density coarse gangue remains close to the slurry surface, and with the aid of wash water, rides over the riffles towards the tails launder at the lower portion of the table. A middling stream is also produced, which is typically recycled back to the grinding circuit for further liberation.

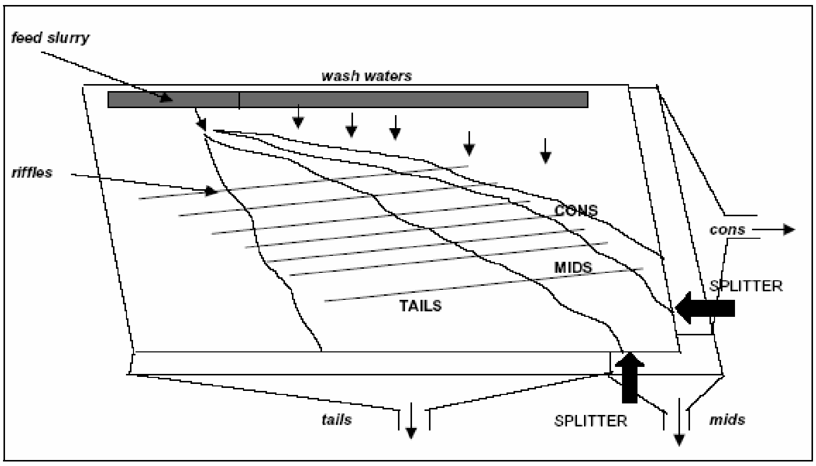


Figure 1 – Illustration of a Typical Shaking Table [2]

The angle of inclination of the table surface, length and frequency of table stoke, and splitter position can all be adjusted to control concentrate yield. Riffle height can also be varied in the table design, with reduced heights being favourable for finer feed types.

Spirals

The first application of the spiral concentrator was reported in 1943, and the first all spiral plant was commissioned in the 1960s [3]. Spirals are typically constructed from polyurethane or fibreglass, and consist of a trough winding around a vertical axis. Typical feed is between 15-45% solids and 3 mm to 75 microns.

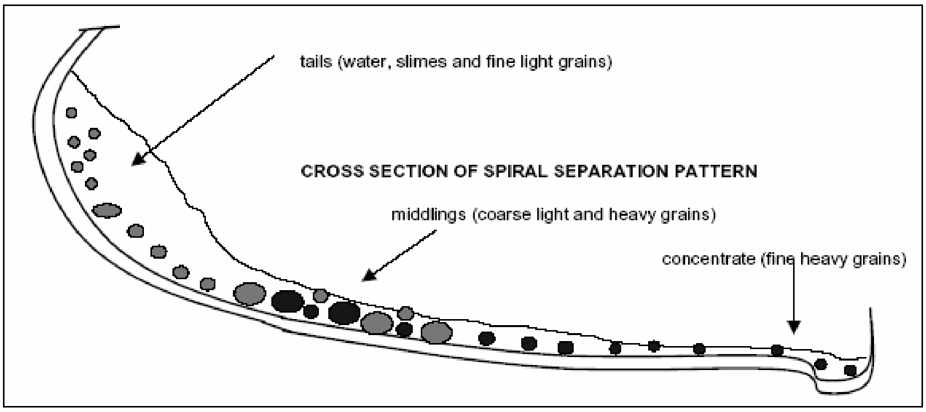


Figure 2 – Cross section of a Spiral Concentrator [2]

Theory of Operation

Slurry is introduced at the top of the concentrator and as the material flows downward a combination of centrifugal and gravity forces act on each respective particle, which results in the segregation of the coarse lights and fine heavies [4]. Separation typically produces four products, a low solids tails stream, concentrate and middling streams, and a higher solids tails stream. These streams are controlled by three cutters or ports in the stream discharge, each of which is adjustable to control grade and recovery. Wash water can be added at the inner edge of the stream to enhance separation.

A wide range of spiral concentrators are available, including double-spiral models, and models that do not require the addition of wash water. In additional to recovering gold, spirals are also commonly used in the coal and mineral sands industries. Vendors include Krebs, Outokumpu, and Multotec.

Pinched Sluices

Pinched sluice type gravity separators were popular during the 1960s and 1970s. Reichert Cones and Trays are both examples of pinched sluices. These separators utilize a sloped design, and contain a narrowing sluicing deck (pinching). Separation occurs with the fine heavies migrating to the bottom of the flowing film, and the coarse lights to the top. Concentrate is removed near the end of the sluice via a slotted opening, while tailings pass over the slot and are discharged over the end of the sluice.

The most common type of pinched sluice separator is the Reichert Cone, which was originally developed for the concentration of heavy mineral sands in Australia. It can be described as a high capacity continuous gravity separator, capable of treating the cyclone underflow stream at capacities as high as 350 tph [5].

Theory of Operation

A Reichert Cone unit normally consists of a series of distributing cone pairs, as illustrated in Figure 3 below. Heavy minerals are removed through circular slots in each cone, which can be adjusted to control the yield. Due to the relative inefficiency of separation, several stages of cones connected in series are usually required for each Reichert unit to achieve adequate metallurgical results. Upgrading ratios are typically in the range of 3 to 1, which usually leads to further concentrate cleaning by either/or spirals and shaking tables or intensive cyanidation.

Feed solids content to a Reichert Cone reportedly should be maintained between 60% and 63% solids by weight, and should controlled to ensure optimum grade and recovery [2].

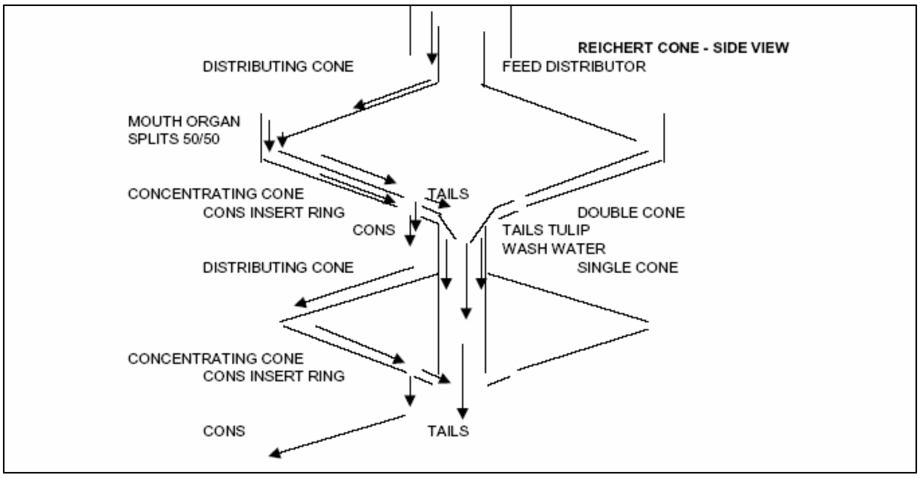


Figure 3 – Cross Section of a Reichert Cone [2]

Jigs

Jigs have been used in gravity separation circuits for well over a century. While effective in certain applications, conventional jigs have several drawbacks such as high water consumption, low availability, high operator dependence, and poor security. During the past decade, innovative improvements to the conventional jig design have been undertaken, allowing for improved efficiencies, higher capacities, and improved security. Both the Kelsey and InLine Pressure Jig are examples of recent improvements to the traditional jig design, and are discussed below in more detail.

Theory of Operation

The main components of a conventional jig consist of ragging material, a ragging screen, diaphragm, and hutch water valve. Feed material of differing densities is fed at the top of the jig in the direction of the ragging screen. Fluidization water from the hutch valve is directed upwards to fluidize the bed. The diaphragm imparts a pulsating and dilating motion on the bed, which results in the separation of light and heavy particles. Heavy coarse particles sink, and migrate through the ragging to the concentrate, and the lighter fine material reports to the tails as overflow. Ragging material rests on top of the ragging screen, and is usually selected on the basis of a density that is intermediate of that between valuable mineral and gangue material to be separated.

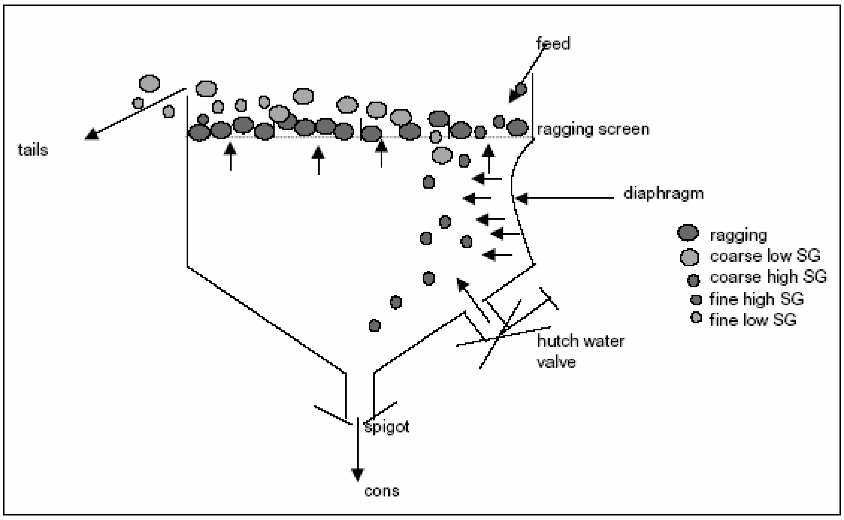


Figure 4: Cross Section of a Typical Jig [2]

<u>Kelsey Jig</u>

The Kelsey Jig, developed during the past 20 years, is a special form of the conventional jig which utilizes a centrifugal ‘G’ force to enhance the mineral separation. Fine particle recovery is improved by overcoming the surface and viscosity effects that limit most gravity separation devices [6].

Theory of Operation

Compared to a conventional jig, the ragging material and screen are vertical for the Kelsey Jig. Feed slurry enters the bowl from the top, and the centrifugal action of the bowl rotation causes feed to distribute onto the ragging. A pulsing action is created by diaphragms that operate as the jig rotates. The heavies work their way through the ragging as it stratifies, and the lights travel upwards towards the tailings outlet.

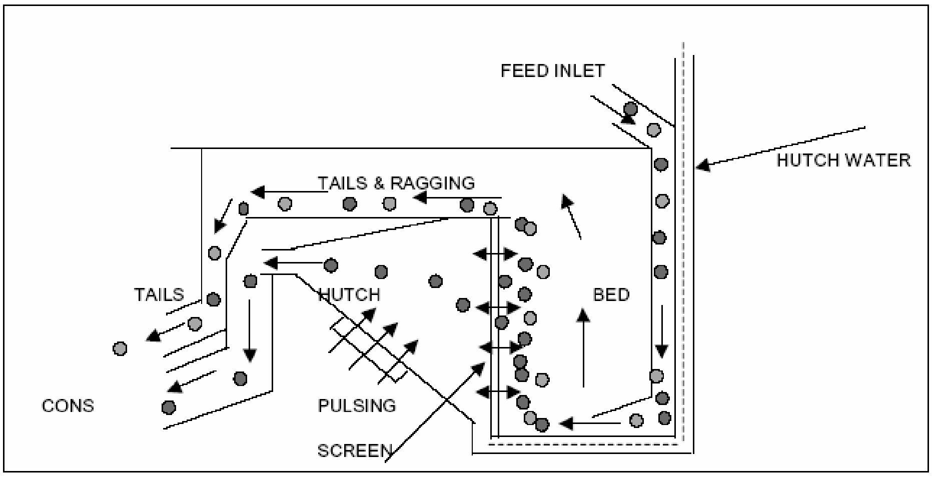


Figure 5 – Cross Section of a Kelsey Jig [2]

<u>InLine Pressure Jig</u>

The Gekko InLine Pressure Jig (IPJ) is a coarse continuous gravity separator. While based on the same principles as traditional jigs, its pressurized design and advanced control system give it many advantages including high recovery, high unit throughput, low water use, close control of operating conditions, low installation cost, low operating costs and high security. The IPJ can be used either in placer deposits as the primary concentrator or in hard rock circuits to treat all or part of the cyclone underflow or mill discharge. As a result of the large range of jig parameters and ragging types possible, the IPJ has successfully been used for a range of minerals, including gold, sulphides, silver, native copper, tantalum, garnet and diamonds. [7]

Theory of Operation

The IPJ is unique in its design and use of jigging concepts. The unit is fully encapsulated and pressurized, and combines a circular bed with a moveable sieve action. The encapsulation allows the IPJ to be completely filled with slurry and water. As a result, slurry velocity is slowed and water surface tension eliminated improving recovery potential. The screen is pulsed vertically by a hydraulically driven shaft. Length of stroke and speed of up and down stroke can be varied to suit the application. Screen aperture, ragging dimension and ragging material can also be altered for the application. An overview is shown in figure 6 below.

Separation of values from gangue particles occurs based on relative density as well as particle size and shape. High specific gravity particles are drawn into the concentrate hutch during the suction stroke of the bed and are continuously discharged. The lighter gangue is discharged over the tailboard to the outer cone. Both concentrates and tailings are discharged under pressure.

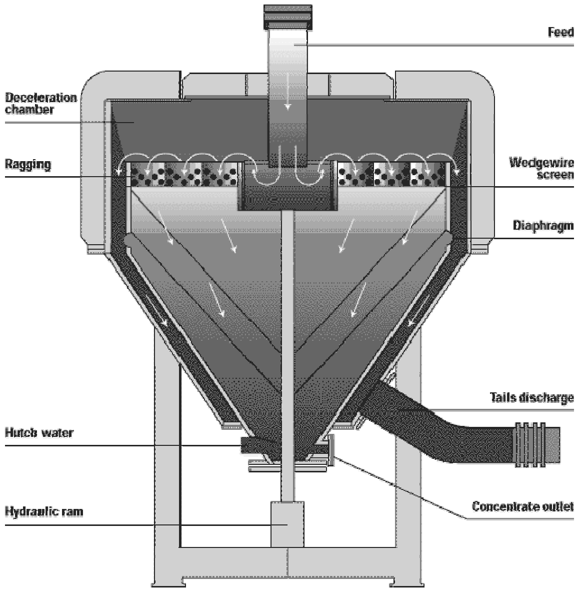


Figure 6 – Cross sectional view showing overview of an IPJ [7]

Advantages of the InLine Pressure Jig include:

- Low water consumption when compared with traditional jigs and most centrifugal concentrators.
- A high degree of flexibility – the IPJ can pull anywhere from 0.5% to 30% of the feed mass as concentrate, resulting in higher overall recoveries and an optimized performance.
- Wide feed and particle size recovery – the IPJ will accept a feed size up to 30 mm, which eliminates the requirement to prescreen the feed. By recovering minerals as they are liberated the potential to recover by gravity is improved and over grinding is eliminated.
- Cost efficient – the IPJ have very low operating costs, at approximately $0.02/tonne processed.

Centrifugal Concentrators

Centrifugal concentrators of various types have been under development during the past 20 years. The success of these concentrators related to the recovery of gravity recoverable gold (GRG) has resulted in a recent resurgence of gravity treatment as method of pre-concentration prior to flotation or cyanide leaching.

Centrifugal concentrators are capable of operating at high speeds of rotation, producing high 'G' forces that allow for the separation of fine GRG (less than 50 microns) that would be previously unrecoverable using conventional jigs, spirals, cones, or shaking tables.

There are several different continuous and semi-continuous centrifugal concentrators available today, each of which differs in their respective design. Only semi-continuous concentrators will be discussed, since they makeup approximately 99% of the centrifugal concentrators presently in use today [8]. These batch units provide a continuous tailings discharge, although feed has to be periodically stopped to wash and remove concentrate from the bowl. Concentrate yields of less than 0.1% are typical, resulting in an extremely high grade smelter ready product.

Knelson

The Knelson concentrator was first commercialized in 1980, and is the most widely used of the three major centrifugal concentrators. Knelson batch concentrators vary in capacity, with their largest unit capable of treating a maximum feedrate of 650 tph.

Theory of Operation

Water is introduced into the concentrator through a series of fluidization holes. This water flow causes fluidization to occur, which limits packing of the feed material within the rings. As material is fed to the concentrator, high density particles work their way through the fluidized bed, and are eventually captured between the individual rings of the cone. Lower density particles are unable to penetrate the fluidized bed, and are subsequently displaced over the top of each ring, producing a continuous tails stream to overflow the inner bowl.

Falcon

The Falcon concentrator was developed in 1983 as a centrifugal concentrator focused on the recovery of fine GRG. The Falcon semi-continuous series of concentrators offer the flexibility of adjustable bowl speeds that can be increased / decreased to operate at gravitational accelerations ranging between 50 and 200 ‘G’. This flexibility allows the operator to target either coarse or fine recovery. Capacities as high as 400 tph are offered.

Theory of Operation

The design of the Falcon is quite different as compared to the Knelson. The Falcon operates at higher ‘G’ forces and utilizes an alternative feed arrangement. Incoming material is fed in a segregation zone along the bottom cone wall, where the dense particles migrate through the gangue and distribute themselves along the wall. At the upper edge of this zone, material is separated into two sections, a lower high density layer and upper low density layer. Material then enters the upper 1/3 of the bowl; also know as the fluidization zone. Fluidization water is only added to the upper 1/3 of the cone to minimize the potential for small gold particles to short circuit with the water flow.

Inline Spinner

The Gekko InLine Spinner is a batch centrifugal concentrator (BCC) used mainly for the upgrading of primary concentrates and the scavenging of table tails. Benefits include zero water consumption, a fast dump cycle time, high recoveries for coarse and fine particles and low operating costs. The InLine Spinner comes with full PLC control and will accept a particle size up to 6 mm.

Theory of Operation

The unit works by feeding slurry into the base of the spinning polyurethane bowl. The bowl operates full of slurry that swirls in a vortex - throwing the dense particles into the riffles located on the bowl's inside face. Cutter bars, operating parallel to the inner face of the bowl, create a turbulent zone that beneficiates recovery by allowing heavy particles to replace lighter particles caught in the g-force of the unit. The riffle depth is designed in such a way that the replacement or separation zone almost reaches the root (rear wall) of the riffle. In this way the maximum amount of heavy mineral is recovered and minimal gangue is recovered to the concentrate. [9]

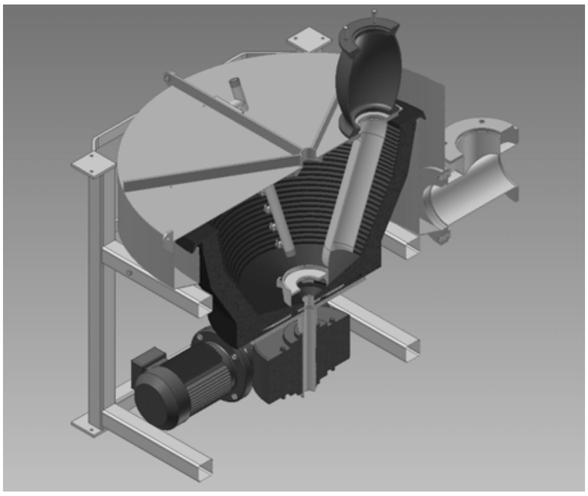


Figure 7 –Cross sectional view of an InLine Spinner [9]

MAXIMIZING GRAVITY RECOVERY

Because of the low installed and operating costs associated with gravity recovery, maximizing gravity recovery can offer significant benefits to a process flowsheet. For example:

- The treatment of certain complex ore bodies with a combination of devices may render previously uneconomic ore bodies financially viable and assist with the recovery profile of transitional ores.
- The addition of a gravity circuit to a simple free gold recovery circuit can boost overall recovery and lower operating costs.

- The addition of a gravity circuit to an existing CIP/CIL plant can provide increased mill throughput without increasing leach capacity.

In order to maximize gravity, complimentary gravity devices, ones that have different recovery characteristics, should be looked at. With a combination of gravity concentrators and or flotation, a combined concentrate containing a significant portion of the total gold in the feed can now easily be treated with leach recoveries expected in the order of 95 percent and above. Table 1 provides a summary of the size ranges the various recovery devices are effective at.

The gravity concentration layout detailed in Figure 8 provides an example of a maximizing gravity flowsheet. It incorporates both InLine Pressure Jigs and Batch Centrifugal Concentrators. The IPJ's treat the entire underflow stream from the hydrocyclones and pull out any coarse free gold and gold carriers. Since the IPJ tails are recycled back to the mill the gravity concentrators have multiple opportunities to recover the gold minerals before they report to cyclone overflow.

On the overflow stream from the hydrocyclones, BCCs are used to scavenge any fine gold minerals; again they treat the entire stream. In this case it is a single pass opportunity to recover the gold minerals. Further recovery on the overflow stream can be achieved by adding conventional or flash flotation.

Cleaning of the primary and scavenger concentrate can be accomplished by adding a third stage of recovery. This can be accomplished by a variety of devices including jigging, BCCs, shaking tables and spirals.

Obviously, this type of circuit is not right for every ore, but for those that contain a high percentage of gravity recoverable gold or sulphides the benefits can be quite staggering. Following are examples of how this type of circuit has been used to great advantage.

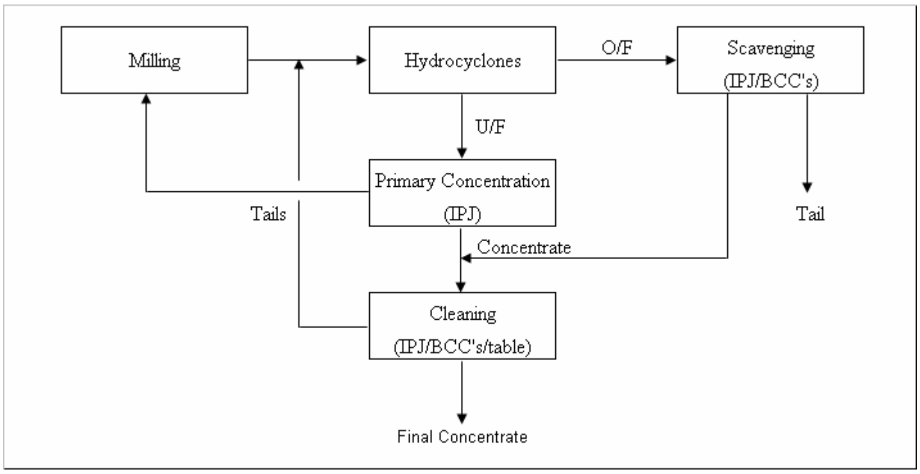
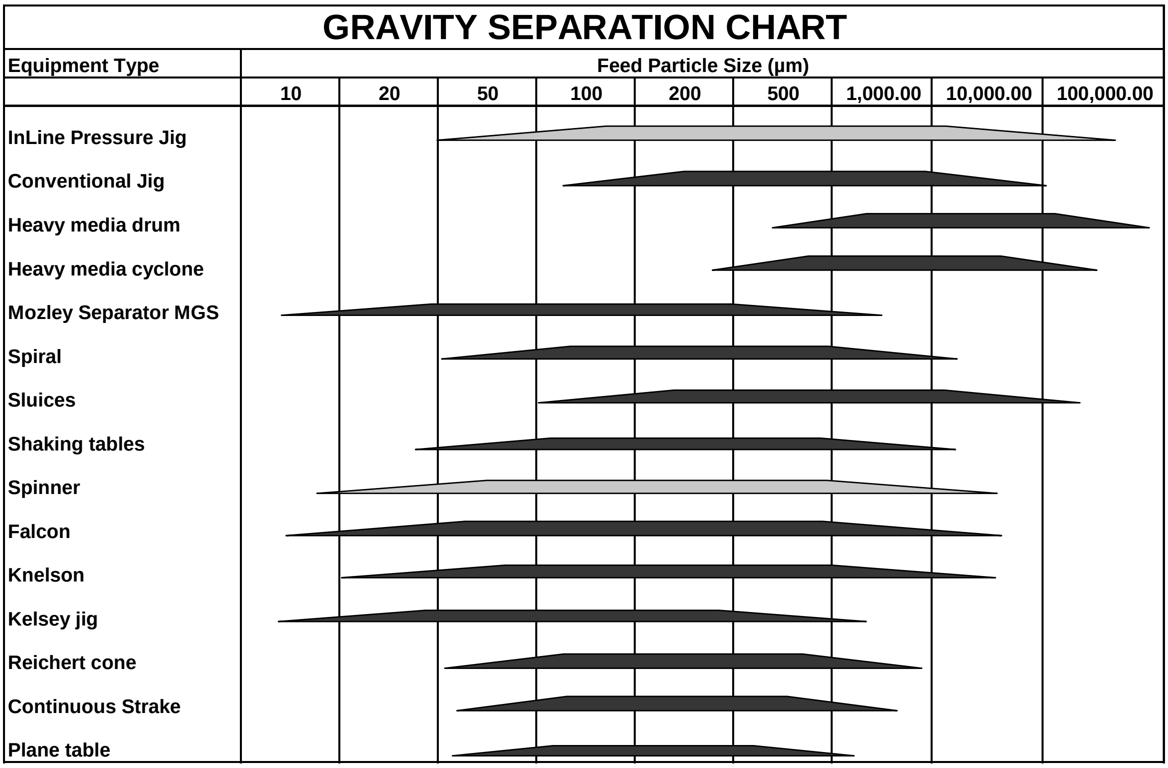


Figure 8- Maximizing Gravity Flowsheet.

Table 1 - Gravity Separation Chart [10]



CASE STUDIES

Beaconsfield

The Beaconsfield Gold Mine in Tasmania operates a gravity recovery circuit ahead of a flotation plant. The gravity circuit plays a critical role in the recovery of gold from the total circuit as the flotation recovery alone drops when the gravity recovery is off-line. Utilizing both InLine Pressure Jigs and centrifugal concentrators allows for a very strong combination of complementary technologies. The gravity circuit at Beaconsfield is made up of an InLine Pressure Jig IPJ1500 that is fed by a separate pump located at the mill discharge. The tailings from the IPJ return to the cyclone feed pump and the concentrate feeds a Knelson Concentrator CD20 that cleans the IPJ concentrate to produce a high-grade concentrate.

In parallel to this circuit is a Knelson Concentrator CD30 which is also fed from the mill discharge hopper and produces a high-grade concentrate. The CD30 tailings are returned to the flash flotation feed, ultimately limiting the amount of free gold miss-reporting to the subsequent Bacterial Oxidation and leaching circuits.

The two high-grade concentrates are tabled daily on a Gemini Table to produce a smeltable grade concentrate. The Gemini table tailings then report to the concentrate re-grind circuit where further gravity separation is carried out with a small InLine Spinner ISP02 and a Knelson CD12. These concentrates also report to the Gemini batch storage for cleaning. A flowsheet for the Beaconsfield gravity circuit is provided in Figure 9.

An independent survey revealed the unit recoveries and performance at the time of the survey. Table 2 shows the recovery by size for each unit in the primary circuit, and is useful in understanding the capabilities of each technology.

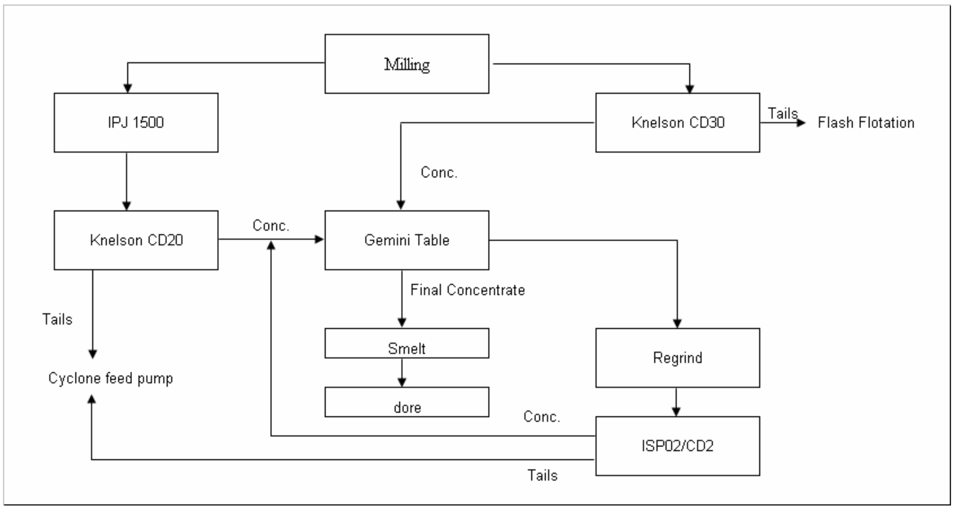


Figure 9 - Beaconsfield Gravity Recovery Circuit

Table 2- Summary of Unit Performance at the Beaconsfield Mine

Unit	Feed Stream	Feed Rate T/h	Unit Rec'y %	Rec. Rate g/h	Upgrading Ratio	P_{80} Gold Rec'd µm	Gold Dist'n[1] %
InLine Pressure jig	Mill Discharge	60	26	382	4:1	320	52%
20" Knelson	IPJ Conc.	4	52	202	72:1	320	28%
30" Knelson	Mill Discharge	60	18	209	110:1	320	28%
Flash Flotation	Knelson CD30 Tail	60	17	161	9:1	106	21%
Cyclone[2]	Mill Discharge	120	93	2211	1.2: 1	320	22%

([1]:as a function of mill feed gold, [2]: the cyclone is treated as a concentrator where "concentrate" is the cyclone underflow and recovery is the cyclone underflow / cyclone feed)

St. Ives

St Ives Gold Mine is currently installing a new 4.5 Mt/a mill with a single stage SAG milling circuit. The circuit relies heavily on gravity due to the coarse nature of the target grind size and InLine Pressure Jigs have been installed in the grinding circuit to recover both free gold and gold carriers. The IPJ concentrate reports to a Falcon SB concentrator for GRG recovery with the tailing of the Falcon reporting for regrind in a tower mill before returning to the leach circuit. The expected overall gold recovery benefit from the gravity circuit is in the order of 3%.

The circuit will also run two Falcon SB units in the cyclone underflow for GRG recovery directly from the circuit. The concentrates from all Falcon units will report to an InLine Leach Reactor for final recovery.

The circuit design has had a heavy focus on gravity and the complete gravity circuit has been integrated into the mill psychology. With a greater reliance on gravity the residence time in the cyanidation circuit will be reduced and hence the overall plant capital cost. The overall recovery is also expected to rise due to the synergistic relationship between leaching and gravity.

Penjom

In 1998 six IPJ1500s were installed at the Penjom Gold Mine in Kuala Lipis, Malaysia to recover both free and sulphide associated gold from the grinding circuit. Batch centrifugal concentrators were also installed to clean the jig concentrates. A flowsheet for the gravity and intensive cyanidation circuit at Penjom is provided in Figure 11. Prior to the installation of the 2 stage gravity circuit, Penjom was using one 30” BCC, which was recovering approximately 10% of the gold in the circuit.

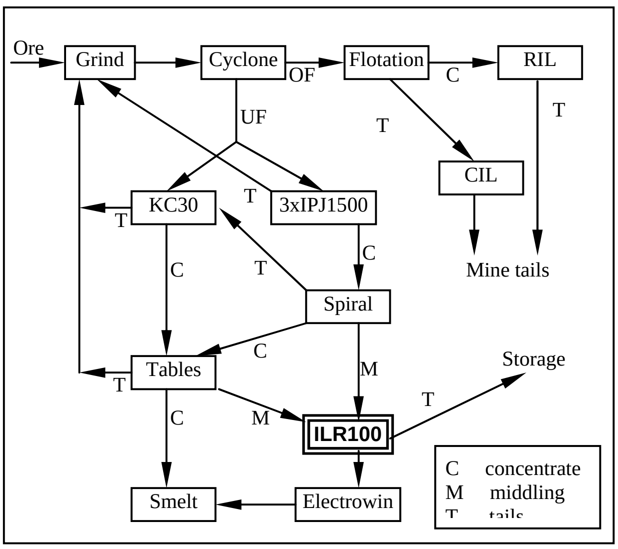


Figure 11 - Penjom Gravity and ILR flowsheet [11]

There was one major reason for installing a two stage gravity circuit at Penjom:

- Extremely low gold recovery – the presence of aggressive, naturally occurring fine organic carbon in the ore was acting as a preg robber in the leach circuit causing recoveries to drop to as low as 75%.

The IPJs were able to produce a concentrate that was low in fine carbon. The centrifugal concentrators would then clean the concentrates further to produce a final concentrate with a grade of 600-800 ppm Au. This concentrate was then fed to a Gekko InLine Leach Reactor for intensive cyanidation.

The addition of the gravity and intensive cyanidation circuit to Penjom resulted in an overall plant recovery increase of 15% to over 90%. The gravity recovery in the plant increased from 10% to 50%.

Conclusions from Case Studies

The case studies presented demonstrate that by combining a variety of gravity devices in one operation you can improve the overall recovery and economics. Other sites have experienced similar gains by incorporating this type of circuit. As with any metallurgical process, however, care must be taken in selecting the appropriate technology for each application.

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