# Kelsey Centrifugal Jig — an update on technology and application

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## Abstract
*The Kelsey Centrifugal Jig is an enhanced gravity concentrator capable of separating fine minerals and/or minerals with relatively small differences in specific gravity. Since the first commercial installation at the Renison Bell tin mine in Australia, development and improvement in hardware has continued, including the introduction of the high-capacity Model J1800 Kelsey Jig. The Kelsey Centrifugal Jig is widely applicable to fine-mineral recovery duties, with key application areas including mineral sands, tin, gold and nickel. Other areas of application include iron ore, base metals, chromite, PGMs, soil remediation and scheelite. The latest developments on the Kelsey Jig are discussed together with a review of recent installations involving Fine gold/sulfide recovery from leach tailings, magnesium mineral removal from nickel sulfide concentrates and high-grade zircon recovery from plant tailings*

Key words: Gravity concentration, Kelsey Centrifugal Jig, Fine-mineral separation

## Introduction
The use of centrifugal force to enhance the effectiveness of gravity separation has been used in a number of mineral separation devices (Silva et al., 1999). The Kelsey Jig is one such device that, with the ability to vary the apparent gravitational field by up to 100 times the normal gravitational force, can facilitate major improvements to separation efficiencies, particularly for very fine mineral feeds and/or for the separation of mineral particles with small density differences. The Kelsey Jig uses the same parameters as a conventional jig but superimposes the additional feature of being able to vary the apparent gravitational field acting on fine particles across a ragging bed by spinning the jigging mechanism (Laplante, 2003).

Since the commercialization of the Kelsey Jig in 1992 (Beniuk et al., 1994), further rationalization of the hardware has occurred through the evolution of a number of features and advanced control systems that can facilitate optimized separation for a range of applications. The Model J1800 MKII Kelsey Jig epitomizes the sophistication that has evolved over a decade of development of this technology.

## Kelsey Jig operation
Feed for the Kelsey Jig flows down a fixed central pipe and is distributed over a ragging bed supported by a cylindrical-shaped screen that is spun coaxially with the rotor. The bed is pulsed and pressurized hutch water is introduced to fluidize the ragging bed and facilitate stratification/sorting. This results in particles of density greater or equal to that of the ragging passing through the ragging bed via the mechanisms of hindered settling and interstitial trickling, which are enhanced by the apparent higher gravitational forces. The denser particles pass through the internal screen to concentrate hutches and then through spigots to a concentrate launder, while the lighter mineral particles are discharged over a ragging retention ring into a tailings launder.

## Operating parameters
The key operating variables on a Kelsey Jig include:

- spin speed,
- pulse rate,
- stroke length,
- ragging specific gravity,
- ragging size and
- hutch water addition.

For a specific duty in a particular application, there will be an optimum set of operating conditions. Although a number of the variables can be determined from the characteristics of the feed materials (feed rate, density and sizing), others require test work to establish the most effective combination or combinations. It follows that the evaluation of potential jig performance is not a trivial exercise. However, recent improvements to Kelsey Jig control systems have facilitated faster rationalization of appropriate operational parameters.

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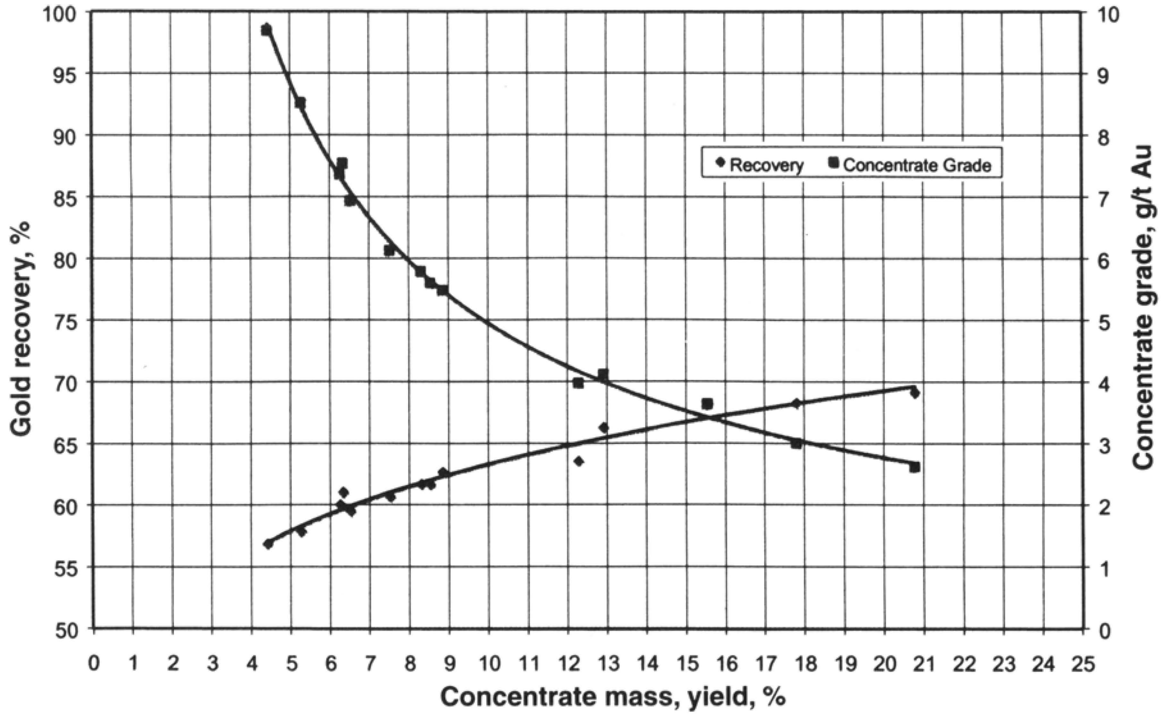


**Figure 1** — Kelsey jig performance – Recovery of gold-containing sulfides from CIP tailings.

## Improvements

In response to previously established limitations to throughput capacity on the earlier Model J650 and Model J1300 Kelsey Jig machines, the Model J1800 development culminated in the first commercial installation in a Bolivian tin operation in 2001. Subsequent Model J1800 machines have been successfully installed and are now operational for the recovery of gold-containing sulfides from CIP tailings and for the upgrading of nickel ore flotation concentrate. Further Model J1800 units are due to be installed early in 2004 for the recovery of zircon from old and new mineral sands plant tailings.

Specific machine improvements, some of which have resulted from experience gained in these first Model J1800 Kelsey Jig installations, include:

- automatic screen cleaning system,
- improved diaphragms,
- upgraded lubrication systems,
- improved internal screen design and
- improved control systems.

Some of these improvements became necessary because of the need to accommodate the requirements for higher throughput capacity (up to 80 t/h), whilst other features have evolved from a desire to introduce more user-friendly operational aspects to the machines.

The effectiveness of these improvements was demonstrated in higher availabilities associated with longer maintenance intervals and the attendant reductions in operating costs.

## Applications

Examples of recent application areas for Kelsey Jigs include the following:

- fine gold/sulfide recovery from leach tailings,
- magnesium mineral removal from nickel sulfide concentrates and
- high-grade zircon recovery from plant tailings.

**Gold/sulfide recovery.** The use of gravity equipment to preconcentrate free (or gravity recoverable gold) in the primary milling stage of gold circuits is now common practice (Broman et al., 1986). However, it is often difficult to define the real economic benefits of installing such equipment into an existing plant due to an inability to quantify increases in gold recovery attributable to the gravity circuit. When considering the installation of equipment to process final plant tailings, the economics are more straightforward.

The challenge in the treatment of final plant tailings is to recover the remaining gold, which is usually very fine and/or locked. While froth flotation can be applied to this duty, such a process can interfere with carbon activity and generally adds complexity to a traditional cyanide leach-CIL/CIP circuit. For this reason, gravity circuits, typically consisting of conventional cone and spiral concentrators in Australia (Butcher and Laplante, 2003), have been employed, often with poor metallurgical performance, particularly with very fine-grained minerals.

However, the Kelsey Jig, with an ability to recover very fine minerals at close density differences, has been demonstrated to be able to meet this challenge. Gravity concentrates produced from leach tailings are generally processed further to recover the gold by (intensive or standard) cyanidation, usually after ultrafine grinding. With this overall processing approach, gravity separation is generally aimed at maximum gold-containing sulfide recovery, at minimal mass yield.

Figure 1 shows typical results achieved with the Kelsey Jig using a range of operating conditions designed to illustrate the performance envelope of the Kelsey Jig in terms of grade and recovery. These tests included various combinations of key variables, including spin frequency, pulse frequency and amplitude, water to tailings rate, ragging type and bed depth, while other parameters were fixed, including internal screen aperture, ragging size, feed rate and pulp density.

This data (Fig. 1) were generated from testing of a CIL tailings stream and demonstrates the ability of the Kelsey Jig to achieve gold recoveries on the order of 60% to 70% at concentrate yields of 5% to 20%. The Kelsey Jig provides the flexibility to target maximum recovery at a lower concentrate grade (and higher mass yield) or to produce a higher-grade, lower mass yield concentrate in a single stage, with a marginal decrease in recovery. Typically, the performance of a Kelsey Jig-based tailings retreatment plant equates to an increase in overall plant fold recovery by >5%.

**Table 1** — Kelsey Jig performance – Processing nickel cleaner flotation tailings.

| Stream | Mass, % | Grade: Ni, % | Grade: MgO, % | Grade: Fe:MgO | Distribution: Ni, % | Distribution: MgO, % |
|---|---|---|---|---|---|---|
| Cleaner floatation tails | 100 | 9.3 | 16.0 | 1.9 | 100 | 100 |
| KCJ concentrate | 38 | 13.5 | 3.5 | 12.5 | 55 | 8 |

**Table 2** — Kelsey Jig performance on nickel ore – Processing flotation feed.

| Stream | Mass, % (wrt feed) | Grade: Ni, % | Grade: MgO, % | Distribution (wrt feed): Ni, % | Distribution (wrt feed): MgO, % | Distribution (wrt size fraction): Ni, % | Distribution (wrt size fraction): MgO, % |
|---|---|---|---|---|---|---|---|
| **Flotation feed:** | | | | | | | |
| –75-µm fraction | 53 | 2.5 | 13.7 | 73.9 | 40.6 | 100 | 100 |
| +75-µm fraction | 47 | 1.0 | 22.6 | 26.1 | 59.4 | 100 | 100 |
| Total | 100 | 1.8 | 17.9 | 100 | 100 | – | – |
| **KCJ concentrate:** | | | | | | | |
| –75 µm fraction | 27.7 | 4.2 | 6.4 | 65.0 | 9.9 | 88.0 | 24.4 |
| +75 µm fraction | 7.3 | 3.7 | 0.7 | 14.4 | 0.3 | 55.0 | 0.5 |
| Total | 35 | 4.1 | 5.2 | 79.4 | 10.2 | – | – |

**Upgrade of nickel sulfide concentrate.** Nickel sulfide ore processing typically involves comminution, followed by multiple stages of flotation to remove gangue minerals, including magnesium silicates such as talc and serpentine. A Ni/Cu separation stage may also be included to recover copper in a separate concentrate. Well-known problems within the nickel production process include:

- loss of nickel due to MgO-based slimes coating nickel mineral surfaces during flotation and
- complications during the smelting process due to low Fe:MgO ratios in final nickel concentrates.

The Kelsey Jig has been shown to be capable of addressing these problems to enhance the performance of existing flotation circuits. Achieving the necessary final nickel concentrate grade from high-talc ores with flotation has been shown to be difficult. The Kelsey Jig, with its ability to separate very fine minerals, provides an alternative to flotation in such cases.

Significant work has been conducted to demonstrate the applicability of the Kelsey Jig in circuits designed to produce high-grade nickel concentrates with maximum Fe:MgO ratios. The most appropriate duty for the Kelsey Jig in such circuits has been found to be the scavenging of tailings from an additional stage of flotation cleaning. This type of circuit enables the flotation cleaner stage to be targeted to produce a concentrate with maximum nickel and minimum MgO content. However, such an operating mode results in lower nickel and iron recoveries. The Kelsey Jig is able to scavenge the cleaner-flotation tailings to increase overall nickel recovery (to typically >90%) and iron recovery (to >75%), while only marginally increasing MgO recovery (from ~25% to ~30%) and maintaining an excellent final (combined flotation and KCJ) concentrate grade.

Typical performance of the Kelsey Jig processing cleaner float tailings material is shown in Table 1. Of specific note is the low distribution (8%) of MgO and the significant increase in Fe:MgO ratio (from 1.9 to 12.5) in the Kelsey Jig concentrate.

Work undertaken on the introduction of the Kelsey Jig upstream in the nickel circuit to facilitate the removal of MgO-based minerals prior to flotation has shown significant potential for a combined Kelsey Jig/flotation approach to processing amenable nickel ores. The data in Table 2 show the separation achievable between Ni and MgO in a single stage of Kelsey Jigs, with recoveries of 79.4% for Ni and only 10.2% for MgO at a mass yield of 35% to concentrate.

The data in Table 2 also highlight the relatively high nickel recovery (88%) from the fine (-75-µm) fraction compared to that from the coarse (+75-µm) fraction (55%), indicating a potential for further improvement of performance by scavenging tailings and/or regrinding a coarse fraction.

In addition to the flotation feed material, the Kelsey Jig can potentially be applied to the processing of intermediate circuit streams. However, in such cases, determination of the impact of such an installation on overall recovery is not readily determinable.

**Zircon recovery.** The recovery of zircon as an accessory value from titanium mineral concentrates has always been compromised when significant levels of the alumino-silicate minerals (kyanite and sillimanite) are present.

The characteristics of these minerals (nonmagnetic, nonconducting) results in them reporting with the zircon and, with near-equivalent hydraulic sizing, conventional gravity separation has inevitably been relatively inefficient. The use of the Kelsey Jig, with its ability to separate minerals with relatively small specific gravity differences, has revolutionized the processing of zircon-containing streams in which accessory alumina minerals (kyanite, sillimanite) are present.

Data illustrating the performance of Kelsey Jigs in this plant tailings retreat application are presented in Fig. 2. These data demonstrate the ability of the Kelsey Jig to maintain production of a high-grade zircon concentrate containing >90% zircon (> 60 % $ZrO_2$) and <3% $Al_2O_3$, at zircon

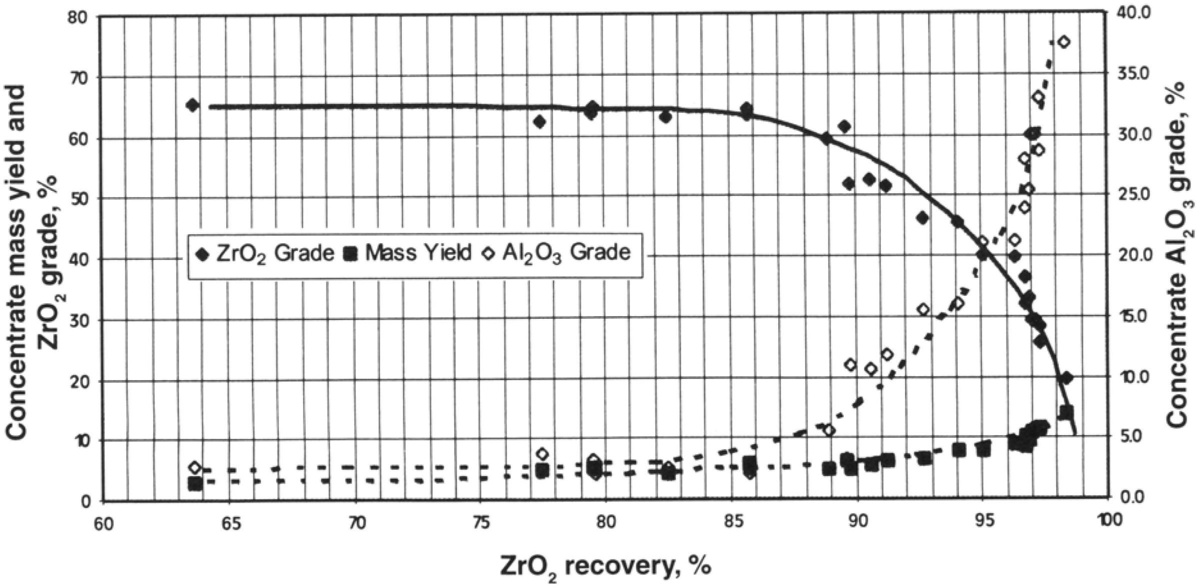


**Figure 2** — Kelsey Jig performance – Separation of zircon from kyanite.

recoveries of ~85% in a single stage of processing from a feed material containing ~3% $ZrO_2$ and ~30% $Al_2O_3$, with a particle size of 80% passing 240 µm and 50% passing 185 µm.

The data in Fig. 2 were generated in a series of tests with the Kelsey Jig using a range of operating conditions with various combinations of key variables, including internal screen aperture, spin frequency, pulse frequency and amplitude, water to tailings rate, ragging size and bed depth, feed rate and pup density

Above 85% zircon recovery, the grade of the concentrate falls in terms of $Al_2O_3$ content. However, even at zircon recoveries in excess of 95%, concentrate mass yields are only ~10% and rejection of alumina exceeds 90%.

The relative ease of zircon recovery and alumina rejection demonstrated by the Kelsey Jig has justified the installation of Kelsey Jigs for the economic processing of old stockpiled and new plant tailings to increase zircon recovery. This single-stage performance also translates well to similar separations within a traditional mineral sands circuit, which typically requires multiple stages of classification and spiral/table concentration to achieve a similar result.

## Conclusions

The introduction and further evolutionary development of the Kelsey Jig has facilitated the reintroduction of gravity separation to ultrafine or otherwise difficult separations. Furthermore, the relatively high capacity of the Model J1800 Kelsey Jig has provided economics of scale for the sophisticated device in several now-proven application areas. The performance of the Kelsey Jig has been demonstrated in these application areas with high levels of separation efficiency.

Future developments are expected to include:

- modularization of Kelsey Jig separating plants for ease of retrofitting into existing operations, for installation in green fields projects and for tailings scavenging duties;
- new applications, including soil remediation and differential separation of fine close-density minerals; and
- complementary applications with other mineral processing technologies, for example, flotation and other gravity separation systems.

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