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**THE RECOVERY OF FINE VALUES FROM TAILINGS STREAMS
BY ENHANCED GRAVITY SEPARATION**

R.G. Richards¹ and T.A. Jones²

¹ Business Development Manager – International, Roche Mining (MT) – Gold Coast, Queensland

² Product Manager – Kelsey Jigs, Roche Mining (MT) – Adelaide, South Australia

Roche Mining (MT)

Evans Deakin Pty Ltd ABN 92 000 002 031
11 Elysium Road
Carrara Queensland 4211
PO Box 2569
Nerang Mail Centre QLD 4211
Australia
Tel: 61 7 5569 1300
Fax: 61 7 5525 3810
Email: sales@roche.com.au
Internet: www.mdmintec.com.au



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R.G. Richards¹ and T.A. Jones²

ABSTRACT

Enhanced gravity separation provides a process to recover mineral values lost to tailings. For processing duties where the valuable constituent particulates are very fine or there are small density or hydraulic differences between liberated mineral species, centrifugal gravity concentrators have found application.

The Kelsey Centrifugal Jig is one such enhanced gravity separation device which has been successfully applied to the cost effective treatment of a variety of tailings streams to scavenge residual valuable constituent minerals. With recent improvements to hardware, including the introduction of the high-capacity J1800 model Kelsey Jig, separation efficiencies and operational availability have improved.

The operation of the Kelsey Centrifugal Jig is discussed and the performance for a number of scavenging applications is reviewed with data from several applications, including:

- Fine gold / sulphide recovery from leach tailings
- High grade zircon recovery from plant tailings
- Scavenging of cassiterite from tin tailings
- Recovery of hematite from iron ore tailings.

Keywords:

Gravity separation, Kelsey jig, tailings

INTRODUCTION

Traditional gravity separation equipment is only generally effective in the recovery of relatively coarse minerals. Past operations using these 1-g devices have produced many tailings dumps around the world that contain significant valuable minerals, predominantly in the finer size fractions. Similarly, many current plants also produce tailings streams that contain sufficient valuable mineral to justify stockpiling and/or retreatment rather than final rejection.

A number of mineral separation devices have utilised centrifugal force to enhance the effectiveness of gravity separation (Silva et al., 1999). The Kelsey Centrifugal Jig is one such “enhanced gravity” separation device, which has the ability to increase the apparent gravitational field (typically by around 50 times) acting on fine feed particles across a bed of ragging material. Utilising the same basic parameters as a conventional jig, as well as the enhancement of the gravitational field (achieved by spinning the jiggling mechanism), enables very efficient separation of both fine minerals and minerals with a relatively small specific gravity differential.

The high efficiency of separation, as well as the introduction of the high-capacity J1800 model, makes the Kelsey Centrifugal Jig an excellent option for processing existing tailings deposits and scavenging current plant tailings streams to recover fine valuable minerals, as well as for removing environmentally unacceptable minerals from plant waste materials.

KELSEY CENTRIFUGAL JIG OPERATION

General description

The Kelsey Jig is fed down a fixed central pipe and feed is distributed upwards over the surface of a bed of ragging material, which is supported by a cylindrical shaped screen. The screen is spun coaxially with the rotor and pressurised water is introduced into a series of hutches behind the screen. This water is pulsed through the ragging bed, fluidising the ragging particles and facilitating stratification / sorting. This results in particles with specific gravity greater than or equal to that of the ragging passing through the ragging bed via the mechanisms of hindered settling and interstitial trickling and exploitation of differential acceleration rates, which are enhanced by the higher apparent 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.

TREATMENT OF TAILINGS STREAMS WITH THE KELSEY CENTRIFUGAL JIG

Fine gold / sulphide recovery from leach tailings

Gravity equipment has long been used to pre-concentrate free (or gravity recoverable) gold in the primary milling stage of gold circuits (Broman et al., 1986). However, quantifying the increase in gold recovery and real economic benefit associated with such circuit changes can be difficult. On the other hand, the economics of treating a final tailings stream to recover additional gold are more straightforward.

Methods such as froth flotation can be applied to the retreatment of gold / sulphide plant tailings, but such methods have inherent complexities and environmental concerns. Consequently, gravity separation techniques have often been employed with cone and spiral concentrators (Butcher and Laplante, 2003), but generally these circuits have exhibited poor metallurgical performance, due to the very fine particle size of contained valuable minerals. The ability of the Kelsey Centrifugal Jig to recover very fine minerals with small density differences offers a potential solution to the recovery of gold-containing sulphide minerals from leach tailings streams. The economic benefits of this application are supplemented by the environmental benefits of reducing the effect of acid mine drainage from tailings dams through the removal of sulphide minerals from waste dumps.

The performance of the Kelsey Centrifugal Jig in the recovery of gold-containing sulphides from CIP tailings is illustrated in Figure 1. By varying appropriate operating parameters, it is possible to achieve a wide range of performance (further illustrated in Table 1), from:

- Relatively low concentrate upgrade ratios at high recoveries, to
- Higher concentrate upgrade ratios at lower, but still quite significant, recoveries

Table 1: Range of Kelsey Centrifugal Jig performance in recovery of gold-containing sulphides from CIP tailings

Performance Focus	Concentrate Upgrade Ratio		Recovery to Concentrate (%)		
	Au	S	Au	S	Mass
High recovery	3:1	4:1	70	80	20
High concentrate grade	10:1	15:1	57	70	5

The ability of the Kelsey Centrifugal Jig to recover fine gold values is shown in Figure 2. These data indicate recoveries of >90% in the 20-53 μm size range. Recovery of Au in the -20 μm size range exceeded 50%, whilst low recoveries from the coarser (+75 μm) fraction are attributed to poor liberation of the Au/S particles with gangue at this particle size.

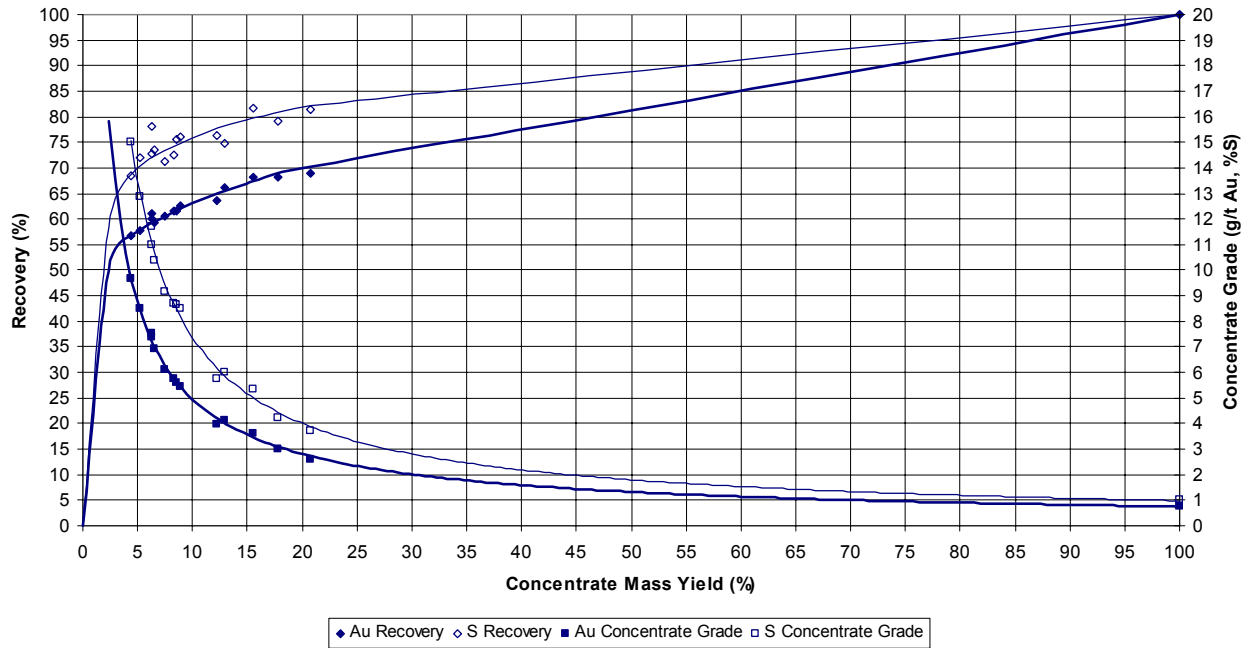


Figure 1: Recovery of gold-containing sulphides from CIP tailings with the Kelsey Centrifugal Jig

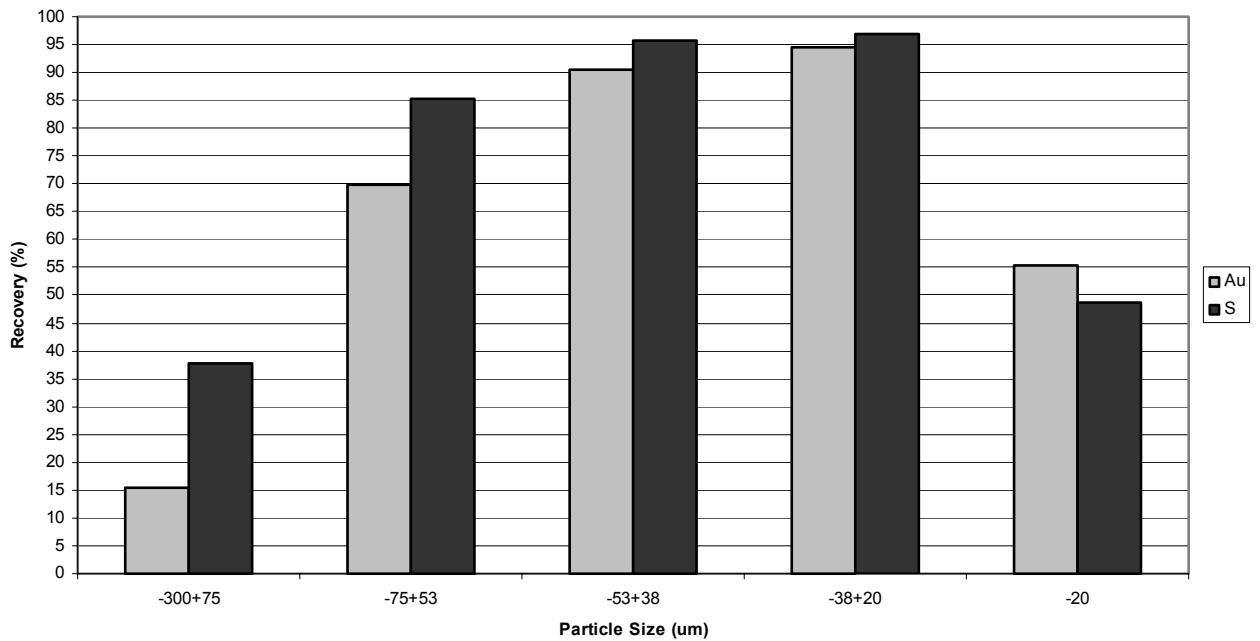


Figure 2: Recovery of gold-containing sulphides from fine size fractions of CIP tailings

The increase in overall plant recovery will depend on how conducive the Kelsey Centrifugal Jig concentrate is to recovery of Au by cyanidation (typically following ultra fine grinding).

High grade zircon recovery from plant tailings

The recovery of zircon as an accessory value from titanium mineral concentrates has generally been compromised when significant levels of the alumino-silicate minerals (kyanite and sillimanite) are present. The characteristics of these (non-magnetic, non-conducting) minerals results in them reporting with the zircon and, with near-equivalent hydraulic sizing, conventional gravity separation has inevitably been relatively inefficient.

Consequently, many zircon-producing operations have generated significant stockpiles of zircon-containing tailings where the prime contaminants are kyanite and/or sillimanite. The use of the Kelsey Jig, with its ability to separate minerals with relatively small specific gravity differences, provides a cost-effective processing option for the retreatment of these tailings stockpiles or indeed the tailings streams which are being directed to these stockpiles.

Data illustrating the performance of Kelsey Jigs in this application are presented in Figure 3. These data demonstrate the ability of the Kelsey Jig to maintain production of a relatively high grade concentrate containing 50-80% zircon at zircon recoveries in excess of 90% and at mass yields to concentrate of between 5-10% in a single stage of processing. As the mass yield to concentrate increases from 5% to 10%, the concentrate grade decreases due to additional recovery of alumino-silicate minerals. However, the corresponding alumina rejection to tailings is in excess of 90% for mass yields <10%. Figure 3 also shows that processing resulted in the production of a tailings stream containing <0.5% zircon, which would generally be acceptable to discard.

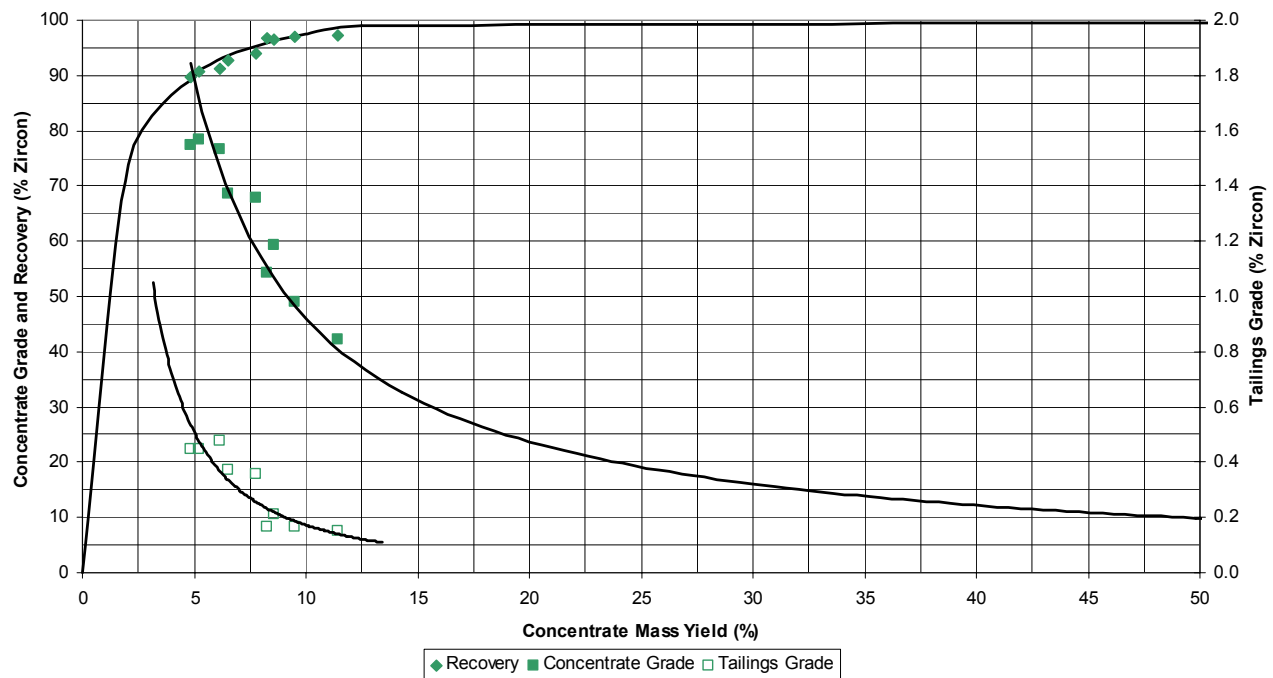


Figure 3: Recovery of zircon from stockpiled alumino-silicate tailings material

Test work has also been performed on tailings deposits containing only 1% zircon. Typical results are presented in Table 2 and illustrate that excellent grade and recovery can still be achieved with such feed material. Alumina rejection to tailings was in excess of 99%.

Table 2: Typical results from Kelsey Centrifugal Jig processing of low-zircon tailings material

	Mass (%)	Grade		Distribution	
		%Zircon	%Al ₂ O ₃	%Zircon	%Al ₂ O ₃
Concentrate	1	75	12	75	0.8
Tailings	99	0.25	16	25	99.2
Feed	100	1	16	100	100

Scavenging of cassiterite from tin tailings

The processing of tin-bearing ores typically involves a large number of physical and chemical unit operations. These ores generally contain sulphide mineral impurities that are removed via flotation, either at the front of the circuit (after grinding to at least 300 µm) or after preconcentration in a gravity circuit. Traditional gravity circuits incorporate hydroclassifiers, spirals and shaking tables and produce concentrate grades in the order of 45-50% Sn (after sulphide flotation). A cassiterite flotation circuit is typically used to recover fine tin minerals not recovered in the gravity and sulphide flotation circuits. Typically, cassiterite flotation concentrates contain 25-40% Sn and are further upgraded before being combined with gravity concentrates.

The Kelsey Centrifugal Jig is ideally suited to the recovery of fine cassiterite and can be applied to a number of different duties within a tin plant, including:

- Preconcentrating tin-bearing minerals prior to sulphide flotation
- Reducing recirculating loads and overgrinding of tin-bearing minerals in the grinding circuit
- Increasing concentrate grades to 60-65+ % Sn
- Processing gravity tailings, reducing or eliminating the need for high cost cassiterite flotation
- Recovery of fine cassiterite from final plant tailings

The results from on-site testing of the Kelsey Centrifugal Jig, treating a final plant tailings material ($d_{50} \sim 40 \mu\text{m}$) containing $\sim 1.2\%$ Sn are presented in Figure 4. The data illustrate the range of results (summarised in Table 3) achievable by a Kelsey Centrifugal Jig in a single stage of processing, from:

- Production of a high grade concentrate at relatively high tin recovery and low concentrate mass yield, to
- High tin recovery and relatively high mass recovery into a lower grade concentrate

Table 3: Range of Kelsey Centrifugal Jig performance in recovery of tin from final plant tailings

	Concentrate Grade (% Sn)	Concentrate Upgrade Ratio	Recovery to Concentrate	
			% Sn	% Mass
High concentrate grade	15	12.5:1	60	5
High recovery	5	4:1	80-90	20

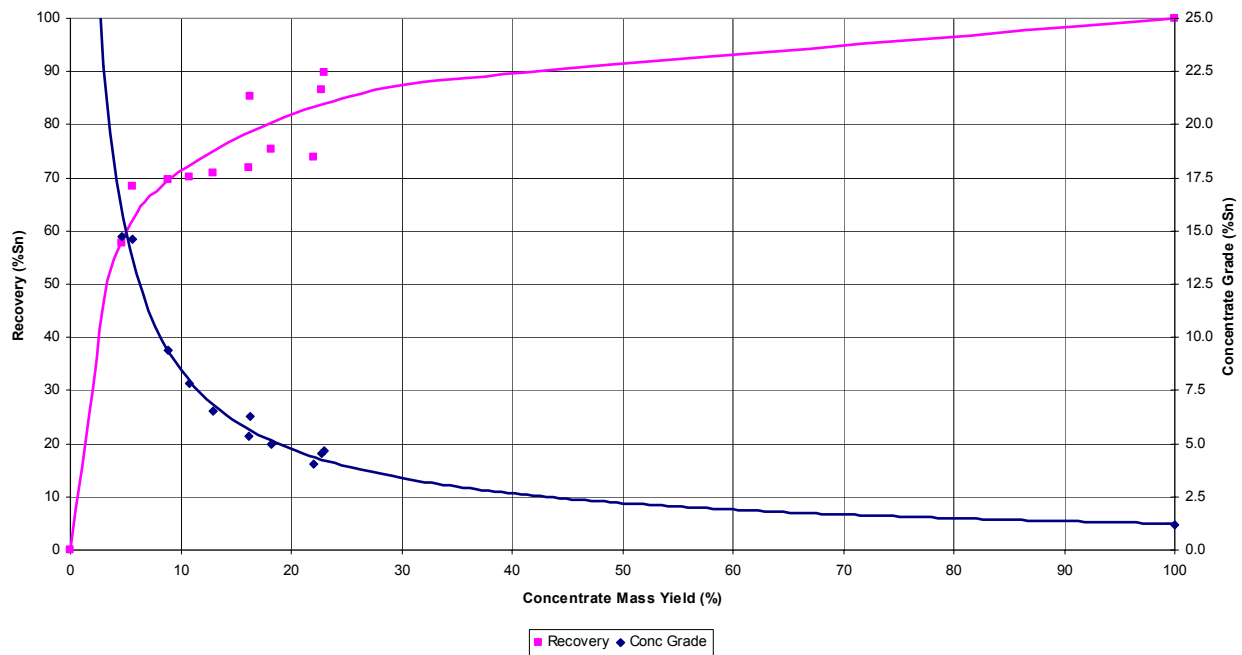


Figure 4: Recovery of tin from final plant tailings with the Kelsey Centrifugal Jig

Separate Kelsey Centrifugal Jig testing of final tailings material containing $\sim 1.4\%$ Sn, from another operation, resulted in an upgrade of $\sim 18:1$ to produce a relatively high grade ($\sim 25\%$ Sn) concentrate at a tin recovery of $\sim 45\%$ and a corresponding mass recovery of $\sim 2.5\%$.

Recovery of hematite from iron ore tailings

The recovery of hematite from iron ore deposits has conventionally been conducted using gravity and magnetic separation. In these operations, separation efficiencies generally begin to fall when the particle size is lower than

approximately 100-150 μm . This is particularly true when there is a requirement to meet high concentrate grade targets. This requirement has become more prevalent with the advent of new refining routes, such as direct reduced iron (DRI). These factors have resulted in the production of large tailings deposits that contain significant fine iron values. The Kelsey Centrifugal Jig has been demonstrated to effectively treat the material contained in these tailings dumps/streams.

The first example of this application involved the installation of a Model J1800 Kelsey Centrifugal Jig to treat a stream that was reporting to final tailings after being subjected to two stages of gravity separation and one stage of magnetic separation. The stream still contained liberated hematite but with a significant proportion of unliberated iron minerals and silica particles which were predominantly coarser than the liberated valuable minerals.

A feed rate of ~55 tph solids was maintained for the trial period which involved several hundred hours operation. Trials resulted in final concentrate grades consistently in excess of 65% Fe and frequently in excess of 67% Fe. Size-by-size grade/recovery data from a set of trial samples (see Table 4) demonstrates the ability of the Kelsey Centrifugal Jig to produce final grade concentrate from a low grade, partially liberated stream in a single stage of processing.

Table 4: Size-by-size grade/recovery data from trial with Kelsey Centrifugal Jig on iron ore tailings material

Particle Size (μm)	Mass Distribution (%wt)			Grade (%Fe)			Grade (%Si)			Recovery to concentrate		Rejection to tail
	Feed	Conc	Tail	Feed	Conc	Tail	Feed	Conc	Tail	%wt	%Fe	%Si
300	4.6	0.0	5.1	13.2		13.2	76.8		76.8	0.0	0.0	100.0
212	19.7	0.3	21.6	8.4		8.4	86.8		86.9	0.1	0.0	100.0
150	24.9	1.2	27.3	6.1	42.7	5.9	92.1	32.9	92.3	0.4	3.1	99.8
106	21.7	3.7	23.6	5.9	57.9	5.1	91.5	15.1	92.7	1.6	15.2	99.7
75	11.7	11.6	11.8	11.1	65.1	5.8	83.2	5.8	90.8	9.0	52.5	99.4
53	5.6	13.9	4.8	21.0	67.2	7.7	66.5	2.5	85.0	22.4	71.6	99.2
45	4.5	30.1	2.0	45.2	68.0	10.6	29.6	1.8	71.6	60.2	90.7	96.4
-45	7.0	39.2	3.8	44.3	66.0	21.8	30.2	3.8	57.6	51.0	75.9	93.6
Total	100.0	100.0	100.0	12.7	65.9	7.4	80.5	4.0	88.2	9.1	47.1	99.5

The capabilities of the Kelsey Centrifugal Jig have further been demonstrated in the results obtained from testing of a very fine (d_{50} ~20 μm) iron ore tailings material containing ~49% Fe. In this a high-grade (>67% Fe) concentrate which met all required targets for elemental composition (Table 5) was produced at a mass yield of 31% and a recovery of 42.5% Fe.

Table 5: Elemental composition of a gravity concentrate produced from a fine iron ore tailings material using a Kelsey Centrifugal Jig

Element		%Fe	%SiO ₂	%P	%S	%K ₂ O	%Zn
Concentrate Grade	Actual	67.2	2.4	0.14	0.07	0.10	0.01
	Target	>63	<4.5	<0.2	<0.2	<0.14	<0.03

CONCLUSIONS

The evolution of enhanced gravity separation technology, specifically in the form of the Kelsey Centrifugal Jig, has provided a means to process tailings streams or dumps to:

- Recover lost fine mineral values
- Efficiently separate minerals with a small specific gravity differential
- Remove environmentally unacceptable minerals

Results from laboratory test work and on-site trials have demonstrated cost effective applications for Kelsey Centrifugal Jigs for the:

- Retreatment of gold-containing sulphide leach tailings
- Recovery of zircon from alumino-silicate mineral dumps
- Reprocessing of tin plant tailings
- Concentration of fine hematite from iron ore tailings streams

In terms of tailings/dump retreatment applications, the Kelsey Centrifugal Jig has also been successfully applied to the:

- Scavenging of nickel flotation tailings
- Recovery of fine free gold from plant tailings
- Retreatment of copper/gold plant tailings
- Recovery of lead and cobalt from flotation tailings
- Recovery of titanium minerals from pigment plant tailings
- Recovery of fine Ti and Fe minerals from calcination dusts and contaminated furnace slags
- Extraction of heavy chromium minerals from stainless steel slag dumps
- Removal of lead from contaminated soils

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