A history of gravity separation at Richards Bay Minerals

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Synopsis

Richards Bay Minerals has been operating gravity separation circuits since 1977, when the first mining concentrator and mineral separation plants were commissioned. Reichert cones were employed to produce a heavy mineral concentrate at the mine and wash-water spirals and shaking tables were used at the mineral separation plant to generate a suitable rutile and zircon-rich concentrate for further processing on dry electrostatic separation machines.

Helical sluices, developed by Wright, provided an alternative to the Reichert cone and all future mining concentrator plants were equipped with these types of units. Roche (MDL) and Multotec developed improved designs of helical sluice and these eventually replaced the wash-water spirals and shaking tables in the mineral separation plant, reducing water requirements and improving plant availability.

This paper describes the gravity separation circuits used at Richards Bay Minerals throughout its history and discusses the advantages and disadvantages of the separation equipment employed. 'New' developments in gravity separation are also discussed, namely the Floatex density separator and the Kelsey centrifugal jig.

Introduction

Gravity separation techniques have been in use in the mineral sands industry for decades; from the Reichert cone to Wilfley tables, Wright sluices and the Kelsey Jig, all attempting that elusive perfect gravity separation. Just as the gravity separation industry evolved, Richards Bay Minerals also evolved in their use and approach to gravity separation. This paper discusses the history of gravity separation at Richards Bay Minerals and briefly comments on future developments.

History

Primary concentration

Richards Bay Mineral's (RBM) first mining concentrator and mineral separation plant commenced operation in 1977 to process ilmenite, rutile and zircon bearing dunal deposits along the northern Natal coast. The orebody contained a greater proportion of non-valuable magnetic heavy mineral in the SG range of 3 to 4 compared to West Australian and Florida USA deposits, making mineral separation more difficult[1].

The deposit was mined using two dredges feeding a floating 2 000 tph concentrator. Concentrator feed was screened and fed to two four-stage circuits consisting of primary, scavenger, cleaner and recleaner Reichert cones (see Figure 1). The primary units were fed at a rate of 80 tph and a density of 60% solids by weight.

Reichert cones are high capacity flowing film concentrators. Slurried feed was distributed around the periphery of the cone surface and fed to two separation surfaces via a 'mouth organ' splitter. Heavy particles separated to the bottom of the film as the slurry flowed towards the centre and concentrates were removed through an annular slot (tulip) and fed onto a single cone for further upgrading. The tailings from the double and single stages were fed onto the next double stage and the process repeated (see Figure 2). Dilution water was fed to each of the single cones at a rate of approximately 7 m^3/h (28 m^3/h for 4DS unit). Reichert cones used in cleaning duties were of the double, single, single (DSS) type allowing further upgrading of the concentrates. Variable slots were also employed and these were automated and used in grade control algorithms. The Reichert cone had low installation and operating costs due to high tonnage per m^2 of floor area and few moving parts. The performance of the units was heavily dependent upon the efficient removal of fine root matter in the screening process. A lost or holed screen panel would

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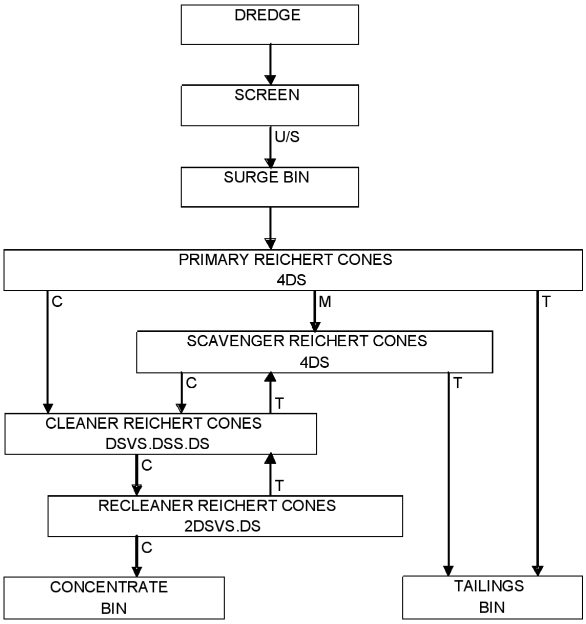


Figure 1—Mining Pond B Cone circuit, D = double; S - single and V = variable

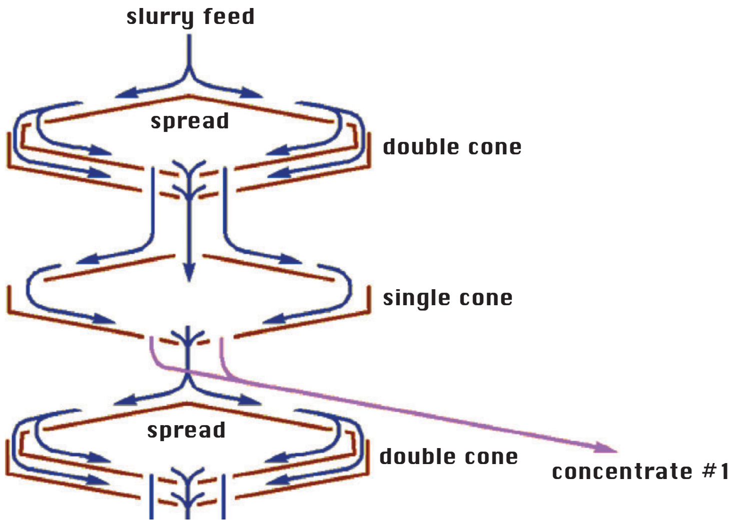


Figure 2—Reichert cone schematic showing the first three stages of a 4DS unit

result in blockage of the mouth organ splitters and inserts, affecting the even distribution of slurry feed to the separation surfaces. Cleaning the aforementioned splitters and slots was a tedious chore not looked forward to by the operating crews. Obtaining clean dilution water for the cones was also difficult at times and blockage of the ring-mains was common. Separation surfaces could be viewed only by opening inspection hatches and peering inside with a torch.

The required capacity of the mining plant was determined by the requirements of the ilmenite smelters and the grade of heavy mineral in the orebody. In order to satisfy the appetite of two smelter furnaces a second mining plant was required and Mining Pond A was commissioned in 1982. The 1 000 tph plant was a single two-stage circuit employing ‘Wright’ helical sluices rather than Reichert cones. Metallurgical test work conducted on site had shown these units to be more efficient and a two-stage sluice circuit matched or bettered four stages of cones. There was also no requirement for dilution water. The drawback to using sluices compared to cones was the increased complexity of the feed distribution system with the many hundreds of starts required.

Increased market share for RBM’s products required further mine expansion. Mining Pond B was upgraded to 3 000 tph in 1986 by utilizing the scavenger cones in primary duty and installing Roche helical sluices to replace them and a 3 000 tph Mining Pond C was commissioned in mid 1988. The new plant consisted of two two-stage circuits using Roche LG5 and MG5 sluices.

To compensate for reducing orebody grades and increased mineral complexity, five-stage circuits were developed for Mining Plants B and C in 1990. A typical flow sheet is shown in Figure 3. New sluices with improved performance became available and high grade units were installed. Further expansion took place in 1992 with Mining Pond D coming on line at a rated capacity of 3 000 tph. Five-stage sluice circuits were again employed using a combination of Roche MG5, HG7 and HG8 units.

The most recent mining expansion took place in 1999 with the commissioning of the 4 500 tph Mining Plant E and the upgrade of Mining Plant A to 1 500 tph giving RBM the capability to process in excess of one hundred million tonnes of sand per year.

The mineral separation plant

The mineral separation plant commenced operation in 1977. Heavy mineral concentrates (HMC) from the mining plants were treated on wet high intensity magnets (WHIMS) to recover ilmenite for the smelting process. The non-magnetic fraction, containing rutile, zircon, quartz and other unwanted minerals was fed to a gravity circuit consisting of primary and scavenger wash-water spirals and scavenger shaking tables. The wash-water spirals used were double-start Roche WW2A in primary duty and WW2B in scavenger duty. Concentrates were removed at every half turn of the spiral by an adjustable splitter. Wash-water issuing from a series of spigots along the inside edge of the spiral provided repeated washing of the concentrate ahead of the splitter, removing lighter gangue minerals to tailings. The final recovery stage was carried out using suspended triple-deck 'Deister' tables constructed of marine plywood. A launder box provided wash-water controlled by wooden interlocking wedges. The table deck angles were individually adjusted. A typical feed preparation gravity circuit is illustrated in Figure 4.

The wash-water spirals gave few operating problems with few moving parts to go wrong. The concentrate splitters sat firmly in their wells and were not easily moved during cleaning of the spiral surfaces. Problems were experienced, however, with the closed wash-water hose and spigots. Slime build-up on the inside of the hose and fine organic matter blocked up the hose and spigots on a regular basis and cleaning proved difficult. The spiral distributors supplied with the units gave uneven distribution resulting in some of the units being over fed, with resultant lowering of metallurgical performance.

The triple-deck Deister tables were very efficient from a metallurgical aspect with a high separation surface area compared to the spiral, but they proved a nightmare to operate in a production environment. The operator or metallurgist had to stand on the product launders to view the separation on the top deck and crouch down with torch in hand to see what was happening on the middle and lower decks. The decks and gearbox were supported by steel cables, which were prone to unequal stretching and required constant adjustment by the mechanical artisans. The motion of the decks caused movement of the wooden wash-water wedges making control of the flow rate very difficult. The wooden decks did not appreciate the hot humid conditions prevalent in Richards Bay and rotting of the units was experienced. During their time in the feed preparation circuits of the mineral separation plant the heavy wooden decks were replaced by fibreglass units with cast polyurethane riffle covers. The wooden wash-water launders, with their uncontrollable wedges, were replaced by drilled stainless steel piping.

A third feed preparation circuit (FPC) was commissioned in 1988 with Roche WW6 spirals and floor-mounted single-deck Deister tables. The new tables gave excellent performance from both a mechanical and metallurgical perspective but still required constant attention from operating personnel to fine-tune their operation.

The Roche WW6 spirals and the Deister tables required a supply of fresh water to promote separation and fresh water was becoming increasingly difficult to obtain. In 1992 the feed preparation modules were redesigned to improve recoveries and reduce the requirement for fresh water. The wash-water spirals and Deister tables gave way to two-stage sluice circuits employing Roche HG8 double-start units as illustrated in Figure 5.

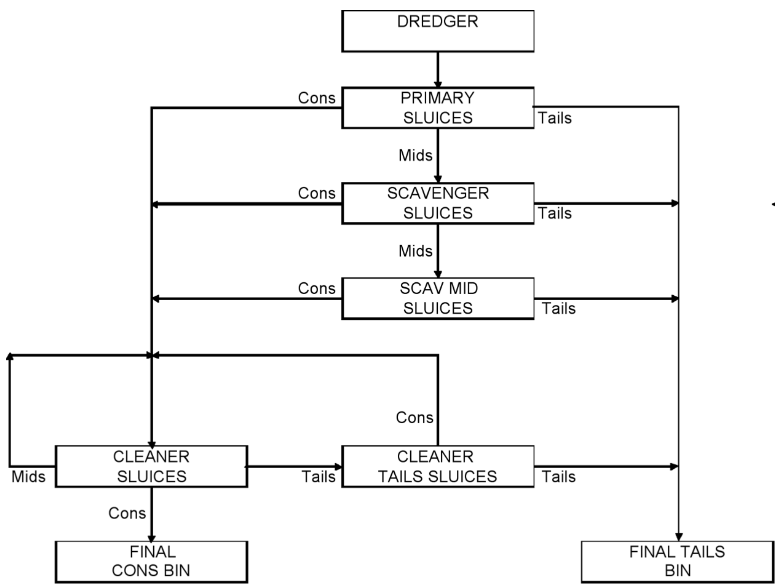


Figure 3—A typical five-stage circuit

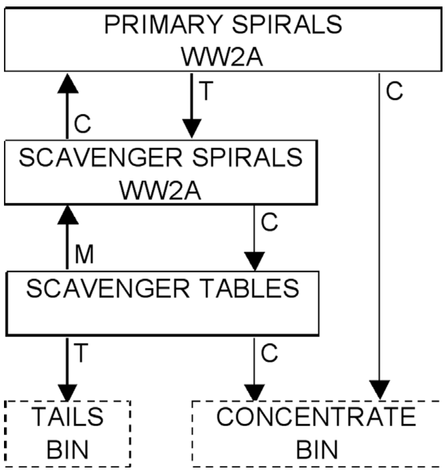


Figure 4—Original feed preparation gravity circuit flow sheet

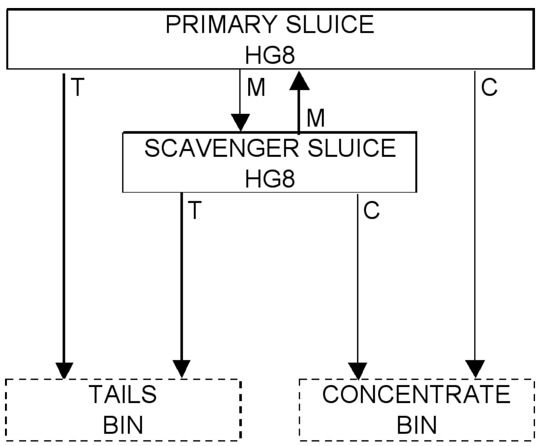


Figure 5—Current feed preparation gravity circuit

The zircon gravity circuit

Concentrates from the feed preparation circuits were dried and treated over electrostatic separators to produce a saleable rutile product and a non-conductor fraction containing zircon. Quartz was upgraded in the non-conductor fraction and gravity separation was required to overcome this. The original gravity circuit consisted of two stages of wash-water spirals and two stages of shaking tables.

The spirals employed were Roche WW2A and WW2B double start spirals identical to those employed in the feed preparation gravity circuits. The tables, however, were double deck Wilfley tables mounted on concrete plinths rather than suspended from the rafters. Access to the bottom deck was also restricted, making set up difficult. The major problems were, however, gear box failures caused by sand ingress and the deck riffle surface. Mechanical availability of the tables was little more than 50%. The riffled deck had been coated with a wear-resistant resin, which unfortunately rounded off the edges of the riffles, making them largely ineffective towards the concentrate end of the table.

The circuit was expanded and upgraded in 1983. A four-stage spiral and single-stage table circuit was developed using Roche WW2 spirals in primary and secondary duty and WW6 spirals in cleaner and scavenger duty. The closed wash-water hoses were replaced with an open launder, making for easier cleaning of the spigots. The table gearboxes were modified in house to prevent sand ingress and the new decks covered with a moulded polyurethane riffle mat. The riffle height and coverage were increased to improve mineral recovery.

The spiral and table circuits were replaced in 1995 by two-stage sluice circuits employing Multotec SC18/7 double-start units. Recoveries were maintained and the water requirement was significantly reduced.

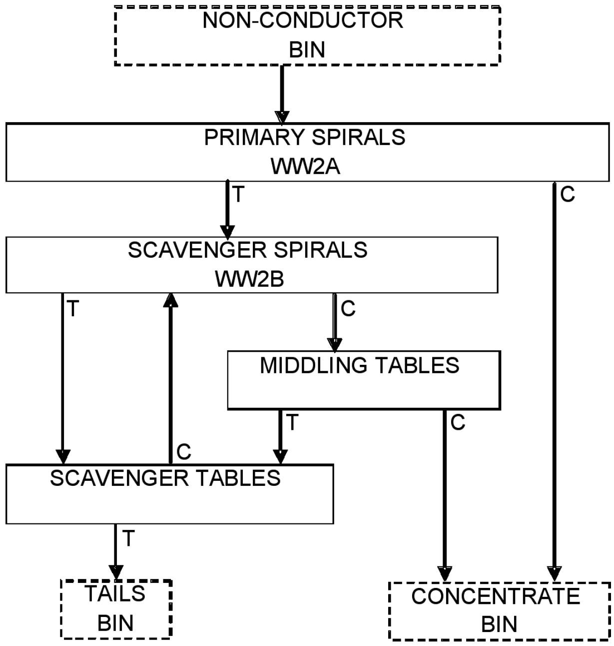


Figure 6—Original zircon gravity circuit

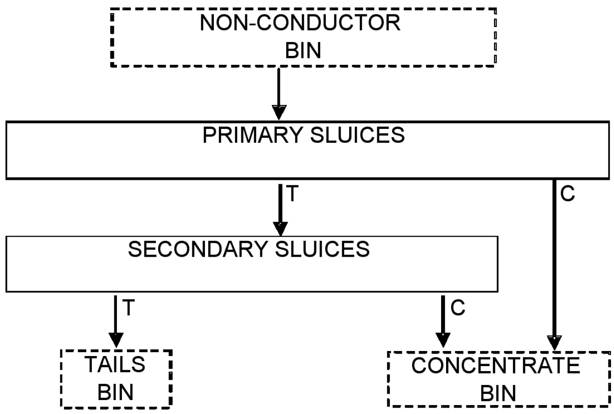


Figure 7—Current zircon gravity circuit

Future developments

Richards Bay Minerals constantly strives to add value to their existing process by investigating new technologies and new applications for older technologies and equipment. Two gravity separation units tested at the operations pilot plant facility were the Carpco wash-water spiral (9000 W) and the Floatex density separator. The Kelsey jig was also tested, but on a bench scale unit. In the opinion of the authors, these units and the Wilfley shaking table represent examples of the basic gravity processing options available. It should be noted that variations of these types of separators exist; however, for the purpose of this article, only the spiral, Floatex and Kelsey jig will be discussed.

Floatex

The Floatex concentrator is a hindered-bed classifier. Feed slurry is introduced tangentially into the unit. Teeter water/fluidization water is introduced right above the cone of the separator, across the total area of the unit. A pressure cell measures the pressure above the teeter water piping and represents the weight or pressure that the solids in the bed exerts on the walls of the unit at the bottom of zone B (separation zone). As heavy particles accumulate inside the bed, the bed pressure rises and when the measured set point is reached, the control valve opens and underflow concentrate is discharged from the bottom of the unit to maintain the pressure in the bed. Figure 8 shows a diagram of this unit.

The Floatex density separator is a relative newcomer to the mineral sands industry; however, it has slowly gained acceptance and is featured in the flowsheet development for the Kwale deposit in Kenya[2]. Elder *et al.*[5]. also report on the use of the Floatex in the mineral sands industry. There are a number of advantages for using the Floatex in a mineral sands circuit, including the following:

- Expected lower maintenance
- Automatic grade control and dampening due to the control principle of the unit
- Fine quartz, which is difficult to reject in a conventional spiral circuit is easily rejected
- Relative ease of installation
- Complements subsequent spiral separation stages.

A disadvantage of the Floatex unit is that it requires good quality process water at consistent pressure and flow for it to operate most effectively, and would therefore need a dedicated water pumping system if these cannot be guaranteed by the overall plant water supply.

Carpco wash-water spiral

The Carpco wash-water spiral is one of the new spirals in the Outokumpu stable, and utilizes the addition of wash-water at the inside of the spiral trough to attempt to improve separation efficiency. The fact that this particular spiral is discussed in this article is purely coincidental and it is used as a baseline for the performance of spiral separators, so that comparisons can be made with other types of separators. Spirals have been used in the titanium minerals industry extensively since their invention, and muchf literature is available explaining their use, history and principles of operation. Papers applicable are Wright[3] and Holland-Batt[4].

Historically, the main disadvantage of a wash-water spiral was the need for the wash-water itself. Maintaining this system by cleaning wash-water nozzles, and keeping piping unblocked could be very labour intensive. Similar to the Floatex density separator, a wash-water spiral also requires good quality process water at consistent pressure and flow for most effective operation, and therefore will require a dedicated water system.

The advantage of the H9000W wash-water spiral is reported by Elder *et al.*[5]. as the improved recovery of fine heavy minerals, which were not recoverable by using conventional spirals.

Kelsey centrifugal jig

The Kelsey jig combines conventional jigging technology with centrifugal forces. The centrifugal forces are created by spinning the bowl of the unit at high revolutions, and the

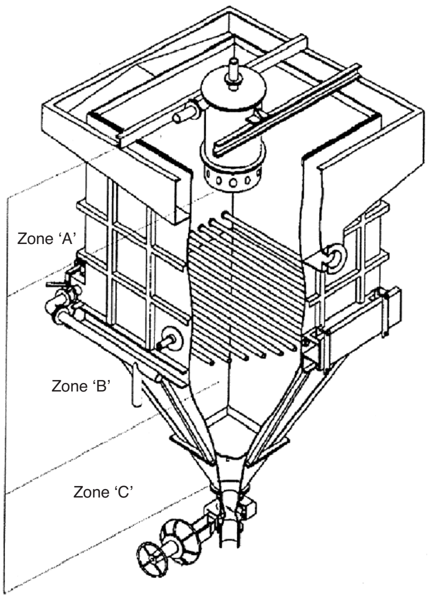
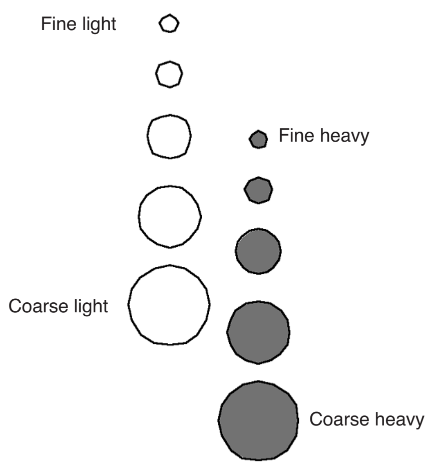


Figure 8—Floatex density separator



Source: Outokumpu Technology

jigging action is produced by pulsing water through a ragging bed. The higher gravitational force increases the effect of the difference in solids density between the particles, and the jigging action constantly accelerates and decelerates the solids particles, improving the efficiency and selectivity of the unit. Figure 10 shows a schematic of the Kelsey jig and its workings.

Over the years, many mineral sands producers have operated the Kelsey jig in their process circuits. A number of these users have resorted to shutting the Kelsey jigs down, due to poor running times, and the need for intensive and quality maintenance. Users that successfully operated these units have managed the maintenance of the jigs well and have shown that the Kelsey jig is a viable process option. The disadvantages of the Kelsey jig are:

Source: Outokumpu

Figure 9—Carpco 9000W spiral

- Relatively high mechanical operating cost due to mechanical failures, and refurbishment of the unit after every 4000 to 8000 hours
- Operator intensive. Units need to be stopped regularly for greasing of bearings and cleaning of the ragging screen, and for most effective operation would probably need a dedicated operator
- Specific ragging material is needed, which at times could be challenging to source
- Good quality clean process water is needed for hutch/pulse water
- Relatively low throughput governed by the rate at which concentrate is produced.

The advantages of the Kelsey jig are:

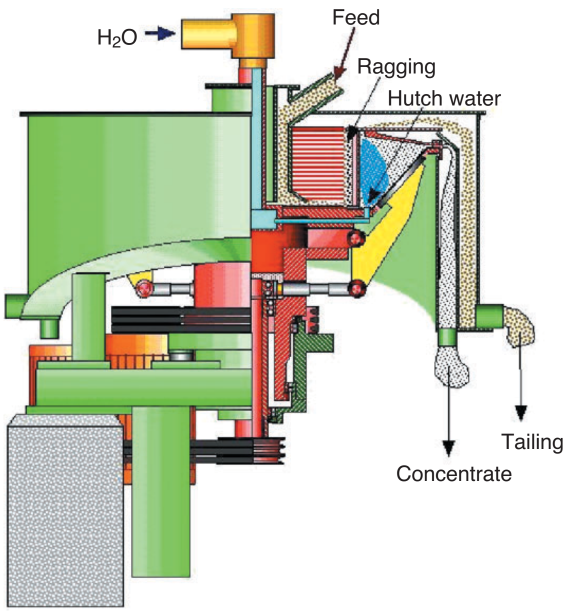
- Improved separation efficiencies over a single treatment stage
- Provides for a simpler flow sheet due to the improved separation efficiency
- Improved recovery of finer heavy minerals.

Test results

Figures 12, 13 and 14 show a summary of recovery vs. yield data for the various test units. By comparing these data it was evident that the Kelsey jig performance was far superior to that of the wash-water spiral and the Floatex. For example, if it is assumed that a 50% yield to concentrate was required, Table I can be compiled from Figures 12, 13 and 14.

The superiority of the Kelsey was expected, seeing that the Kelsey jig makes use of additional G-forces, pulsing water and a ragging bed to effect separation. Balderson[2] also reported on the superior separation efficiencies of the Kelsey jig.

Due to the nature of the particle selection process in the Floatex unit, and the up-flow created in the unit due to de-watering and fluidization water, it was expected that some fine valuable mineral would not be recovered in the



Source: Roche Mining MT

Figure 10—Kelsey centrifugal jig

Table I
Recovery data

	Recovery					
	Yield	Ilmenite	Rutile	Zircon	M/O	Quartz
Wash-water spiral	50	84.5	72.3	81.4	38.8	12.3
Floatex	50	83.7	69.7	87.8	29.6	5.3
Kelsey jig	50	98.8	92.0	99.6	31.6	3.6

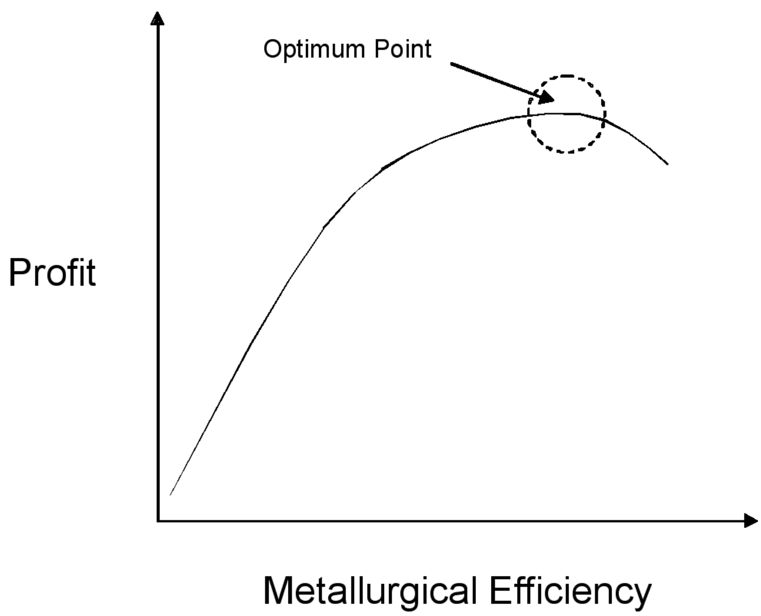


Figure 11—Profit vs. metallurgical efficiency

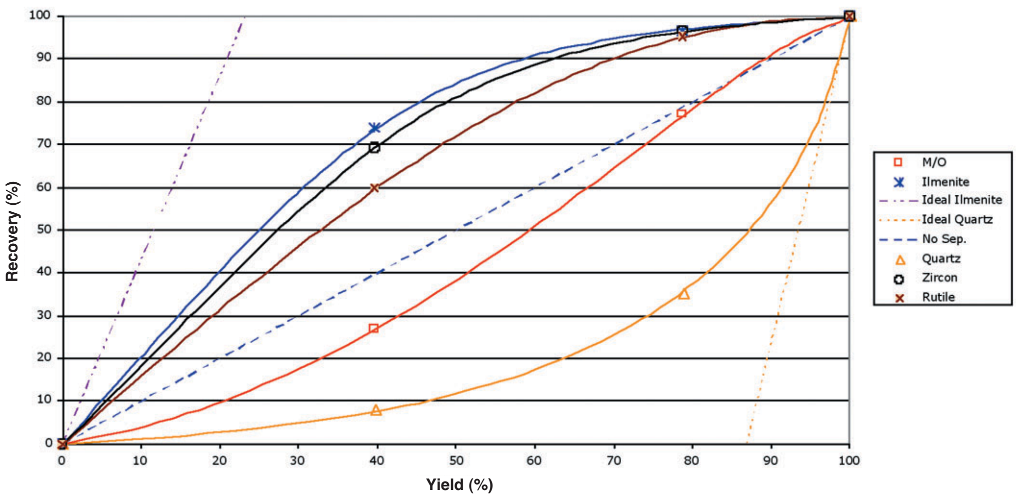


Figure 12—Summary of test data for the wash-water spiral

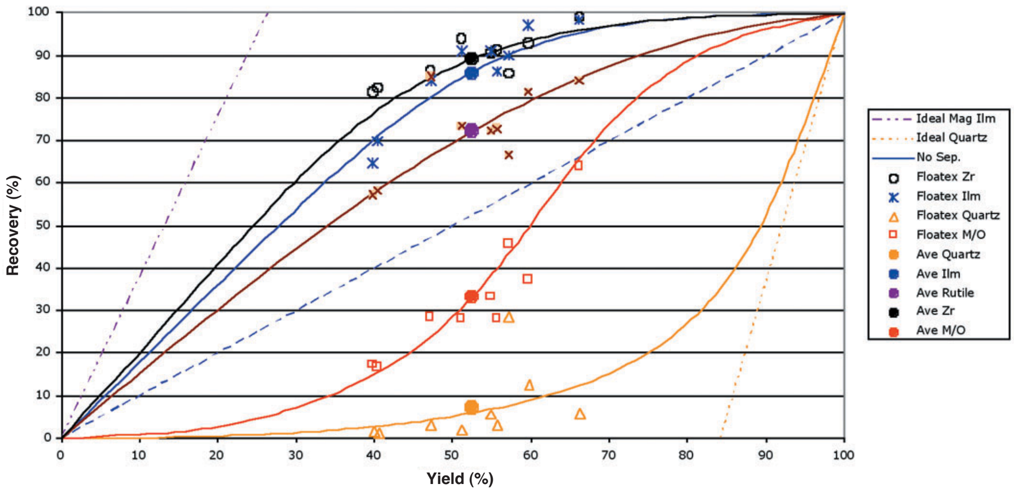


Figure 13: Summary of test data for the Floatex hindered bed settler

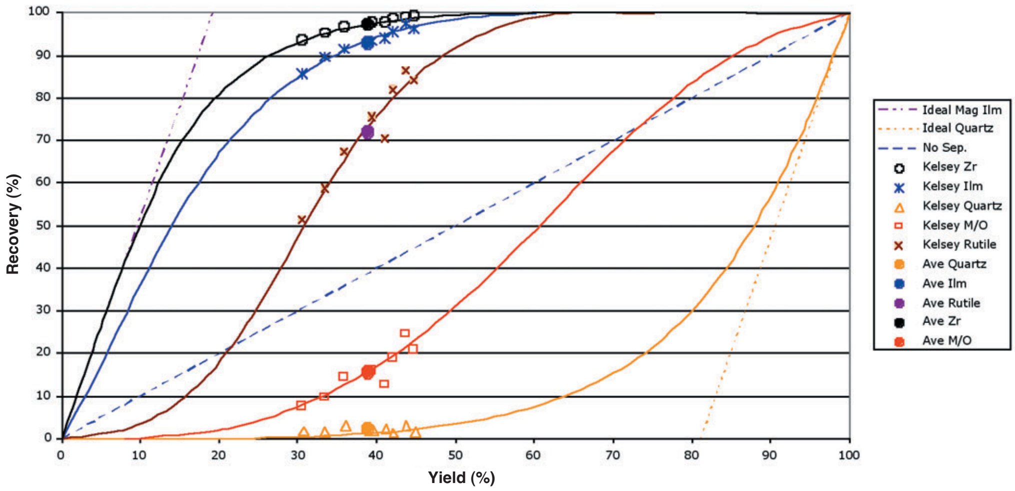


Figure 14—Summary of test data for Kelsey jig

underflow. It should, however, be kept in mind that finer mineral particles in a conventional dry mill would not be easily recovered, and it is not always economical to pursue them. One of the problematic contaminants in the dry mill is fine quartz which is difficult to reject in a conventional spiral circuit. The Floatex showed that it could very effectively reject this fine quartz, and although coarse quartz was concentrated in the underflow, subsequent spiral stages would easily reject this.

Generally it can be said that each of the units discussed, has it own area of application, and none of the units can purely replace the other. Even though the Kelsey jig is the most metallurgically efficient, it is more expensive and maintenance intensive to operate. The challenge for engineers is to fashion the most efficient circuit, while still maintaining profitability (Figure 11). This principle will also govern which processing technology you will use in a specific situation. With a more concentrated stream, it might be more economical to use a Kelsey jig than operate a spiral circuit; in a less concentrated stream, this might be the opposite. Economics will make the decision for us.

Conclusion

This paper has shown how Richards Bay Minerals' gravity separation circuits have evolved with time, effectively mirroring the advances in technology. RBM pioneered the use of all-sluice concentrator plants in the 1980s and continues to seek new and innovative ways to improve their operations to gain a competitive advantage.

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