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HIGH CAPACITY GRAVITY SEPARATORS
A REVIEW OF CURRENT STATUS

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ABSTRACT

Flowing film gravity separation devices, including sluices, spiral separators and cone concentrators have undergone significant development over the past two decades, and are now well established technology in the processing of a wide variety of fine mineral feeds.

The recent resurgence of interest in cone concentrators has resulted from a recognition of the benefits that this high-capacity and low-cost separator offers. These attributes are re-examined with reference to a number of recent innovative applications.

The benefits of high unit capacity are also reflected in the evolution of high capacity spiral separators which similarly offer operational simplicity and plant sizing and cost savings. These benefits are accompanied by demonstrable gains in metallurgical performance.

Examples of recent applications of high capacity cone and spiral systems are examined and metallurgical performance data presented. © 1997 Elsevier Science Ltd

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INTRODUCTION

The use of gravity separation as a mineral concentration technique declined in the first half of this century due to the development of differential flotation, leaching, and heavy-media separation systems.

In Australia in the 1950's, the mineral sand industry faced declining ore grades and increasing costs. This situation motivated the development of various forms of pinched-sluice separators. Perhaps the most outstanding device evolving from this era was the cone concentrator, which dominated as the most cost-effective gravity separator in the mineral sands industry over a 20-year period from the mid 1960's [1].

Alternative Applications

During the 1980's, the availability of this relatively low-cost gravity separation technology, together with the relatively high operating costs and emerging environmental constraints associated with the use of flotation and leaching systems, lead to the use of cone concentrators in non-traditional areas [2,3,4,5].

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This is exemplified by the so-called "gold towers" (cone/spiral circuits) installed as pre-concentrators ahead of flotation specifically to recover gold and silver values from base-metal sulphide ores in several Scandinavian operations [5,6].

Spiral Separators

The 1980's also saw major developments occur in spiral separators, and the mineral sands industry moved towards favouring spiral separators ahead of cone concentrators for use in wet concentration plants primarily due to the greater upgrading capability of spiral separators compared to cone concentrators.

Current Situation

Both cone concentrators and spiral separators have undergone continuous improvements over the past 20 years, leading to the development of a variety of spiral models for specialist applications, and to the availability of high capacity spirals and the 3.5m diameter cone concentrator which has a unit capacity of up to 300 t/h of solids.

CONE CONCENTRATORS

The Reichert cone concentrator is a high-capacity, low-cost gravity concentrator developed in the 1960's in response to the need to process low-grade mineral sand deposits for the efficient recovery of titanium minerals and zircon. Having no moving parts, operating costs and energy requirements for plants using cone concentrators are relatively low and manning requirements minimal.

The first cone concentrators were limited in operating flexibility, and were somewhat difficult to service. Subsequent modifications, involving the introduction of new (wear-resistant) materials of construction and variable inserts (splitters) addressed the maintenance issues and resulted in greater flexibility in on-stream control [7].

All the early cone concentrators were built to a 2m diameter design. This size remains today and has a unit capacity of 50–90t/h solids.

The cost and metallurgical benefits offered by this device resulted in its widespread acceptance in mineral sand operations throughout the world over the period 1960–1980. In the latter part of this period, the use of Reichert cones was extended to applications other than mineral sands concentration; with cones being used in the beneficiation of fine iron ore, tin and tungsten minerals, gold and silica sands [3,8,9,10]. The relatively high capacity of cone concentrators makes them well-suited for scavenging trace quantities of valuable, high-density minerals from tailings streams.

The operating benefits associated with the capacity of the 2m diameter cone concentrator were capitalised in the development of a higher capacity 3.5m diameter machine in 1980.

Separation Mechanism

Designed for the treatment of particulate material generally finer than 2mm in size and to recover fine heavy mineral particles down to approximately 30 microns, the cone concentrator effectively consists of a series of circular pinched sluices. The separation mechanism involves a combination of hindered settling, intergranular trickling and flowing film concentration resulting in a stratified flowing bed in which the fine heavy particles are concentrated at the bottom of the pulp stream and are removed by an annular slot.

Implicit from the geometry of cone concentrator are the relatively high flow velocities and relatively thick films that occur on the concentrating decks. This results in quite a small (but significant) degree of stratification in each pass over a single cone surface. However, by repeating this effect several times, the degree of upgrading reaches a practical level. Furthermore, by arranging the cone concentrator stages in different configurations (corresponding to various internal flow arrangements), cone concentrators can be assembled in ways that can either be more appropriate to rougher or scavenger separation stages (where the recovery of heavy minerals in more significant) or, alternatively, in configurations for where the focus is on upgrading, such as in the cleaner or recleaner stage of a beneficiation plant.

The longer stratification length of the 3.5m diameter cone concentrator deck results in a greater upgrading than can be achieved by a 2m diameter cone deck. It follows that equivalent overall metallurgical performance can be achieved in a 3.5m diameter cone containing fewer stages than for a 2m diameter cone assembled in the same configuration.

Benefits

The relatively high-unit capacity of the 3.5m diameter cone concentrator, together with its potential metallurgical performance, offer the following design and operational advantages:

- Minimal floor space requirements,
- Simplified feed distribution and product laundering,
- Ease of metallurgical control,
- Low energy consumption due to high feed pulp densities,
- Low total water demand,
- Easier and cheaper tailings disposal systems.

Applications

Cone concentrators have been utilised in areas other than their traditional application area of mineral sands since the early 1970's, and the higher capacity 3.5m cone concentrator has continued to be utilised in a variety of application areas since its introduction in the early 1980's.

Primary Gold Recovery

The classic "Gold Tower" application for the first installation of 3.5m cone concentrators was at OK Tedi Mining Limited's concentrator at Tabubil, Papua New Guinea. 2 x 3.5m cone concentrators formed the primary stage of a gravity circuit which proved very effective in the recovery of "coarse" gold from the grinding circuit established for the early gold-rich period of the OK Tedi mine life. The cones, arranged in a DSS.DS configuration, processed 500 t/h of screened/classified SAG mill discharge to achieve a stage upgrading of 2.9 for gold.

In a similar application, the most recent plant utilising 3.5m cones in a gravity circuit is the Cyprus/Amax Fort Knox Gold operation in Alaska where a single 3.5m cone (3DS configuration) forms the first stage of a multi-stage gravity circuit to recover coarse gold from 300–330 t/h of screened/classified SAG mill discharge.

Gold Tailings Retreatment

The most recent gold tailing retreatment installation was commissioned in April, 1996 at Placer (Granny Smith) Pty Limited's operation at Laverton, W.A. The multi-stage cone/spiral circuit utilises a single 3.5m cone concentrator (3DS configuration) in the rougher stage for recovery of a gold-containing sulphide-rich gravity concentrate from cyanide tailings. Operating at a feed rate of 160–250 t/h of leach circuit tailings (80% passing 120–150μm) the rougher cone concentrator achieves upgrades in the range 1.5–2 at gold recoveries of up to 75% from tailings containing 0.2–0.3 g/t Au.

Mineral Sands

Arising from a need to supplement feed to one of their existing land-based wet concentration plants, RGC Mineral Sands Limited installed a pre-concentration plant in early 1996 to upgrade low-grade ore. The plant incorporates 3 x 3.5m rougher cone concentrators (3DS configuration) fed in parallel at up to 1000 t/h of feed containing 4% of heavy minerals (+4.0s.g). Typically, the cone plant enables 65–70% mass rejection to tailing, whilst recovering 85–95% of the heavy mineral (+4.0 s.g.)

Silica Sand Classification

In an unusual application discovered after some years of operating 2m diameter cones in their silica sand beneficiation plant, Cape Flattery Silica Mines Pty Ltd now use 3.5m cone concentrators to effect a size classification as the first stage in the production of two grades of glass-making silica sand feedstocks. The 2 x 3.5m diameter cones (DSDD configuration) treat a total of 720 t/h new feed solids. Two streams, coarse and fine, are produced from the 3.5m cone and proceed to separate downstream circuits. Typical sizing data are shown below in Figure 1.

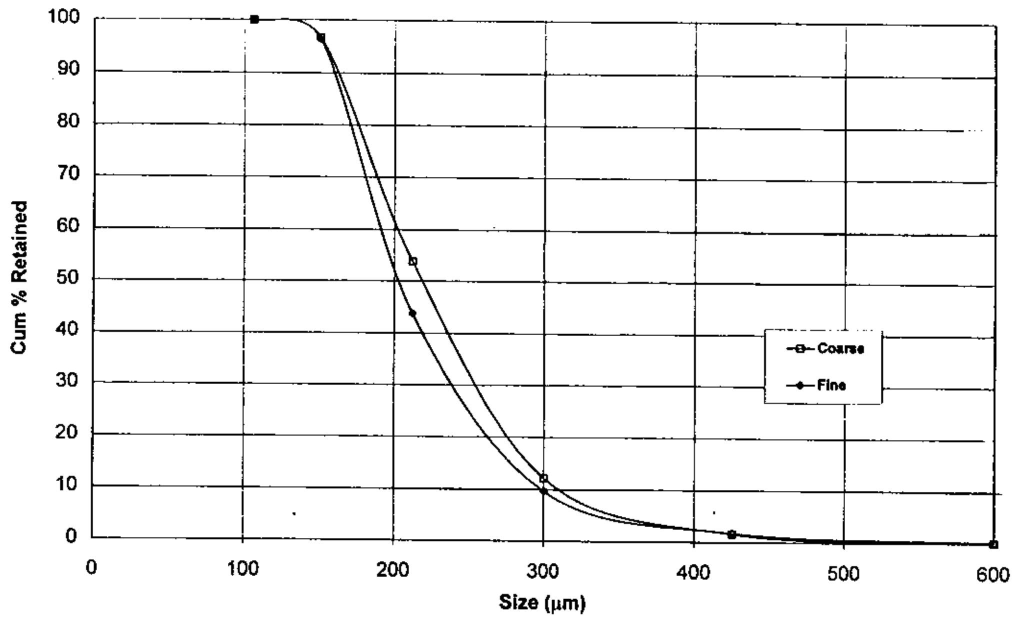

Fig.1 Typical sizing data from 3.5m cones (DSDD) at Cape Flattery Silica Mines:

These data indicate that only a limited degree of classification is being achieved. Nevertheless, this is clearly significant to the market and, furthermore, provides for improved performance from the downstream spiral circuits which treat the two classified streams for the rejection of an iron-containing heavy mineral fraction.

SPIRAL SEPARATORS

The spiral separator was first introduced by Humphreys in the 1950's with applications in iron ore and chromite sands. Although the early designs were simple, with insensitive profiles, the virtues of the concept were quickly recognised and spirals were adapted to the treatment of many other minerals [9].

Developments in spiral technology have been primarily of Australian origin. Light-weight materials were introduced (the original units were made from cast iron or cast cement) and trough profiles have been refined to address more demanding metallurgical duties. The improvements in trough profiles have brought about several marked advances. Wash water has been eliminated in most applications, and significant increases have been realised in both separation efficiency and unit feed capacity. Major increases in feed capacity (per unit floor space) have also resulted from the development of twin and triple-start spirals (i.e. multiple troughs per column).

The most sophisticated spirals available today incorporate continuously-changing profiles to accommodate changes in behaviour of the slurry as it descends. Other features of modern spirals may include auxiliary concentrate or tailing splitters, repulpers and stream .diverters.[1] Materials used in modern spiral manufacture include PVC, fibreglass and highly wear-resistant polyurethane.

Separating Mechanisms

Categorised as flowing film concentrators, (along with cone concentrators and other types of sluices), spirals are characterised by predominantly laminar flow down an inclined surface. The particle bed is transported in a continuous stream, under the force of gravity, rather than by mechanical means [11].

Current understanding of the mechanism of separation on spiral separators involves *primary* and *secondary* flow patterns [12]. These flow patterns allow for dilation of the particle bed and provide opportunities for separating mechanisms to occur. The primary flow is that of the slurry descending the incline of the trough. Secondary flow occurs radially across the trough. The upper, more fluid layers move away from the centre while the lower, more concentrated layers (especially where particles are in contact with the solid surface) move towards the centre. Stratification occurs and the secondary flow causes shearing of the strata, resulting in bands of higher density particles reporting to the inner region of the trough. Figure 2 shows a schematic representation of spiral flow patterns.

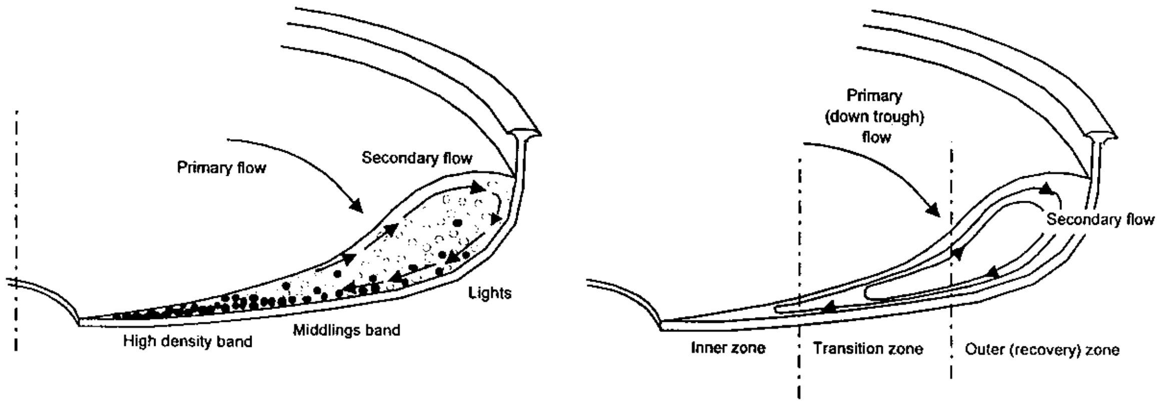

Fig.2 Primary and secondary flow patterns in a spiral trough

Conceptually, the cross section of the slurry on the trough can be divided into three zones. The inner zone is occupied by a slow-moving bed of particles overlaid by a free motion region. The rising component of the flow has a certain capacity to lift and transport. At any given size, lower-density particles have a greater likelihood of being lifted and transported away from the centre by the secondary flow.

In the outer region, referred to as the recovery zone, particles must settle into the lower layers in order to be transported towards the centre of the spiral. Particles of higher density have a high propensity to migrate into the lower, inwardly-moving stream.

The intermediate transition zone, under normal operating conditions, exhibits a free motion region above a bed region that is relatively less concentrated and more fluid than the inner zone. Particles in this region move with the secondary flow and are transported according to their relative position within the bed.

High Feed Capacity Spirals

Significant advances have taken place in spiral technology since their origins in the 1950's. The major developments have focused on improved metallurgical performance, or separation efficiency. Over time, the improvements have become progressively more subtle, predictably obeying the law of diminishing gains. By shifting the focus more recently to another aspect of performance, namely unit feed capacity, significant gains have also been achieved.

High Capacity Coal Spirls

Spiral separators were introduced into the coal industry in 1980. The original units were of a similar diameter (approximately 650mm) to the conventional mineral spirals of the time. The LD2 coal spiral was one of the most popular and most successful of the early models. Comparative testing has shown superior performance by the more recently developed, higher capacity LD4. High capacity, wide diameter spirals have now been universally adopted in the coal industry.

The data in Table 1 are derived from a test program conducted on an Australian coking coal of a size range −2000 +250μm. For this material, the higher capacity spiral (LD4) matched, and in many cases, exceeded the metallurgical performance of the lower capacity spiral (LD2), and at feed rates 2 to 3 times greater.

TABLE 1 Comparative performance of High/Low Capacity Coal Spirals.

LD4 (High Capacity)			LD2 (Low Capacity)		
Feed rate t/h	s.g. cutpoint d50	Ep	Feed rate t/h	s.g. cutpoint d50	Ep
2.7	1.70	0.13	1.4	1.57	0.27
2.8	1.65	0.17	1.5	1.65	0.18
3.0	1.64	0.14	1.5	1.81	0.25
3.1	1.65	0.14	1.5	1.80	0.28
3.8	1.86	0.16	1.5	1.80	0.21
4.4	1.80	0.16			
4.7	1.83	0.22			
4.7	1.83	0.22			

The LD4 spiral is a 5-turn model. The more recently developed 4-turn LD7 spiral model incorporates improved trough profile design along with other materials-handling features. Comparative data (Figures 3a and 3b) demonstrate equivalent metallurgical performance of these two spiral models.

High Capacity Mineral Spirals

The recently developed high capacity MG2 model spiral separator was designed primarily for a roughing duty with the proposed advantages of:

- Greater overall feed capacity for a given plant space resulting in reduced capital expenditure.
- Simplified feed distribution and product laundering.
- Improved operator control over metallurgical performance.

The MG2 spiral is a six turn unit with a diameter of 950mm. The design incorporates two auxiliary concentrate splitters after the second and fourth turn.

Performance Assessment

The MG2 spiral occupies just under twice the area of a conventional lower capacity spiral such as the MG4. It follows that, in order for the scale up to be deemed successful, the feed capacity should exceed twice that of a conventional spiral, for equivalent metallurgical performance [13].

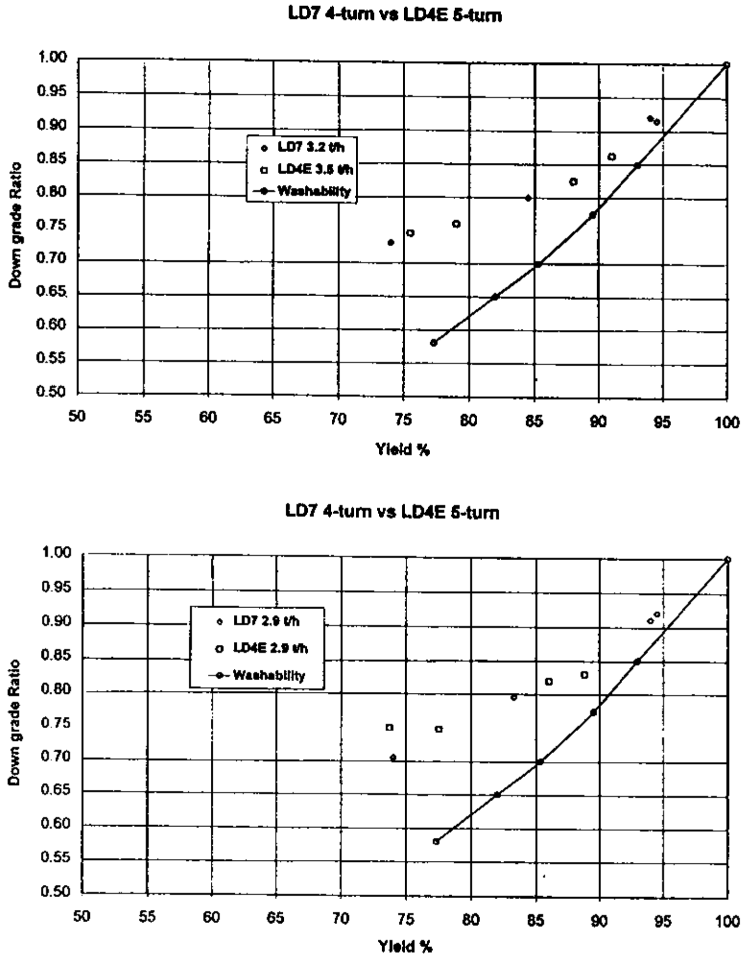

Fig.3a and b Performance comparison between 5-turn and 4-turn high capacity coal spiral

The data presented in Figure 4 are derived from comparative testwork conducted on an Australian mineral sand using MG4 and MG2 spiral separators.

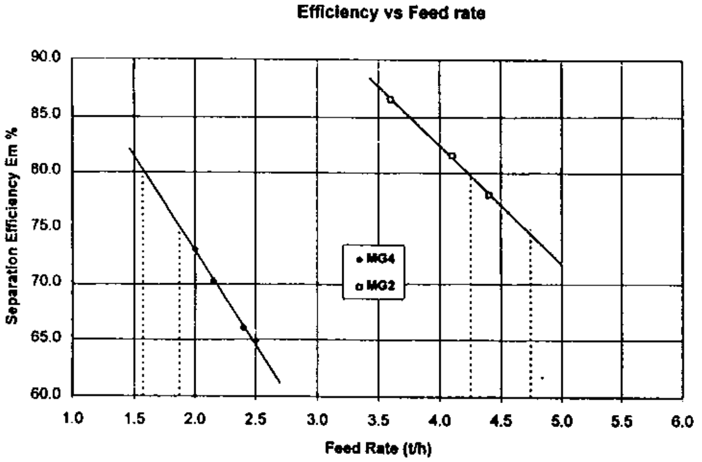

Fig.4 Comparative performance of High/Low Capacity Mineral Spirals.
(after Holland-Batt[13])

It has been previously established that the relationship between feed rate and separation efficiency, on a spiral, is linear [14]. Extrapolation and interpolation of the above data can therefore be utilised with some confidence to draw comparisons at nominally 80 and 75% separation efficiencies. The summarised data (Table 2) indicate, that for the material tested, the MG2 can treat 2.7 times as much feed as the MG4 at a separation efficiency of 80%. At 75% separation efficiency, the MG2 has a feed capacity of 2.5 times that of the MG4.

TABLE 2 Summary of Performance Data for High/Low Capacity Mineral Spirals.
(after Holland-Batt[13])

Efficiency	MG2 Spiral Feed rate (t/h)	MG4 Spiral Feed rate (t/h)	Capacity ratio MG2/MG4
80	4.3	1.6	2.7
75	4.7	1.9	2.5

The results of testwork on another feed material, in an application where H.M. recoveries were the critical criteria, are summarised in Table 3.

TABLE 3 Comparative Performance for H.M. Recovery on High/Low Capacity Mineral Spirals.

Mass % Dist'n to Concentrate	HM Recovery %	Feed rate (t/h)		Capacity Ratio MG2/MG4
		MG2	MG4	
30	75	5.25	2.53	2.08
30	80	4.68	2.13	2.20
30	85	4.14	1.76	2.35
30	90	3.63	1.40	2.59

For the material tested, a mass distribution to concentrate of 30% is in the region of peak efficiency for both spiral models. These data indicate a clear performance benefit for the MG2 spiral (compared with the MG4 spiral) with this benefit increasing at higher H.M. recoveries.

The comparisons discussed above are based on the assumption that an equivalent number of spiral troughs are fitted to a column. In fact the geometry of the larger MG2 model spiral is such that it is feasible to fit 4 troughs to a column thereby increasing the feed capacity (per unit area of floor space) by an additional 33% over and above the advantages already demonstrated.

INSTALLATION BENEFITS OF HIGH CAPACITY CONES AND SPIRALS

The installation of high capacity cones or spirals results in a number of tangible benefits. Plant layout is significantly simpler and cheaper with respect to feed distribution and laundering systems. Reduced complexity is also a welcome factor during plant commissioning and operation. A reduced number of separation units improves the degree of control over metallurgical performance. With fewer adjustment points the chance of performance variation is minimised. The capital costs of separation equipment, including pumps, can be reduced by up to 20%.

One of the more significant advantages is the smaller plant footprint. In a cursory engineering study for a mineral sand wet gravity separation plant (designed to treat 1200 t/h at a head grade of 5% HM), comparative plant area requirements were determined for four separate circuit options. The derived data (Table 4) indicate that a 16% saving on floor space is possible by using 3.5m cones in the rougher stage (option 3) compared to using low-capacity spirals. Furthermore, a 26% saving is indicated with the quad-start MG2 high capacity spiral (option 4). These plant area reductions would result in significant savings in capital expenditure.

TABLE 4 Comparison of plant area requirements for four circuit options.

Circuit Option	No. of Circuit stages	Rougher stage equipment	Required total plant area (m^2)	Percentage of base option
1	4	192 Triple-start MG4 spirals (Base case)	380	100
2	5	16 x 2.0 diameter cones	360	95
3	5	4 x 3.5 m diameter cones	320	84
4	4	72 quad-start MG2 high capacity spirals	280	74

Reductions in operating costs are also indicated for plants in which cone concentrators are used in preference to spiral separators. With cone concentrators being fed at relatively high pulp densities (60–65% solids), the use of cones results in substantially reduced volumes to be pumped compared to an all-spiral plant. As a consequence, energy savings of between 10 and 20% can be realised. Furthermore, reductions in water requirements of between 10 and 30% in the overall plant can be expected. It follows also, that the volumes of tailings are reduced and therefore significant cost and operating benefits are associated with the tailings disposal and water management systems.

CONCLUSION

The high unit capacities of more recently developed cone concentrators and spiral separators, offer significant capital cost savings for gravity separation plants incorporating this technology.

Operational benefits also arise from simplicity and ease of control, minimal water demand and lower energy requirements.

These advantages have been utilised in several unconventional application areas for 3.5m cone concentrators in recent years.

High capacity spiral separators are now well accepted in the coal industry world wide, and high capacity mineral spiral separators are now available.

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