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IMPROVED GRAVITY SEPARATION SYSTEMS UTILIZING SPIRAL SEPARATORS INCORPORATING NEW DESIGN PARAMETERS AND FEATURES.

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Improved gravity separation systems utilizing spiral separators incorporating new design parameters and features.

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ABSTRACT

Refinement of design parameters and features has resulted in the development and commercialisation of spiral separator models that offer enhanced performance for a number of application areas.

Examples of recently developed spiral separator models are presented together with comparative performance data.

The utilization of spiral separators providing improved performance offers significant costs and operational benefits for process plants. Examples of process flowsheet changes that have resulted from the incorporation of recently developed spiral separators are discussed.

INTRODUCTION

Spiral separators have been widely accepted as one of the most flexible gravity separation devices for several decades. The benefits of these mineral separators for fine mineral beneficiation include:

- low cost
- high separation efficiencies
- ease of operation

These factors have lead to the development of a range of spiral separators designed for specific applications and / or duties. Included within these specific design units are spiral models for the beneficiation of fine coal[1], the processing of ultra-fine minerals[2] and the treatment of larger throughputs of fine mineral[3]. Each spiral separator model has a unique trough profile, pitch and features to ensure efficient separation over a design duty window.

The availability of mathematical modelling techniques[4] and computer-controlled profile generating systems has facilitated the rapid design, production and testing of a range of spiral separators that involve geometrically complex trough profiles. In addition, the development of performance-enhancing features has ensured spiral separator against commercial maturity.

Shortcomings of spiral separators include:

- relatively low unit throughput
- need for multi-stage processing
- lack of control of product flow pulp density
- limited acceptable feed size range

These aspects are addressed in some of the recently developed spiral separators.

Furthermore, there are demonstrable beneficial plant design implications resulting from the utilisation of new spiral separator models. These factors can result in plant capital and operating cost deductions which potentially ensure more favourable financial analysis for both greenfield and process plant revamp projects.

Design Parameters

The design parameters of spiral separators can be classified into: trough dimensions, added features, ancillary equipment and manufacturing method / construction materials.

Trough Dimensions

The critical dimensional details of spiral separator troughs include:

- diameter
- pitch
- down-trough slope/s
- cross trough profile/s
- diameter of centre column / width of working surface

Some of these factors are interdependent. In general, recent design spiral separators have complex geometrical trough profiles that change throughout the length of the spiral trough.

The pitch (vertical distance between successive turns) determines the down trough slope and slurry velocity. This factor also influences the residence time of the feed slurry as does the number of turns.

The trough diameter impacts on the trough profiles and downtrough slope and thence scale-up for higher capacity is not a trivial geometrical exercise.

Features

A number of features have been incorporated into the design of separators.

Modular Feed Box – The feed point to a spiral separator is an area where the feed slurry is normally relatively fast flowing. The duty of the feed box is to dissipate some of the energy in the feed slurry and present the feed to the top of the separation trough in a homogenous and quiescent slurry distributed across the width of the spiral trough. The modular feed box system achieves this objective with replaceable componentry that can withstand a high impact abrasion.

Slide Splitter – The removal of concentrate fractions at various points down the spiral trough without risk of flow disruption caused by the splitter itself or trash material built up around the splitter is facilitated using slide splitter systems in which the splitter channel is an integral part of the spiral trough.

Pivotal Splitters – The use of pivotal splitters at the bottom end of the spiral trough facilitates the use of a ganged system in which splitters on a multi-trough spiral assembly can be adjusted simultaneously and equivalently.

Water Splitters – The utilisation of a splitter mounted horizontally on the inside of the outer wall of a spiral trough facilitates the division of the spiral tailings into a relatively high pulp density “sand tailings” fraction and a low density “water tailings” or “slime tailings” fraction.

Repulpers – The installation of repulpers on spiral troughs improves the separation efficiency of spiral separators. The function of repulpers is to capture and divert a portion of water from the high velocity tailing stream and introduce it to the relatively sluggish middling stream in order to fluidise the particle bed and re-initiate separation mechanisms.

Product Box – The collection and laundering of the product fractions from spirals (concentrate/s, middlings, tailing/s) is facilitated by product boxes which are designed to collect common fractions from the separating troughs of multi-start spiral separators. The design of this feature is critical to ensure the effective directional change and joining of fast-moving slurries whilst minimising splash and impact abrasion.

Integral Edge – The elimination of separate edging componentry has been facilitated by design changes that provide for a return on the outer edge of the spiral trough. This feature has helped eliminate leakages of water / slurry under the edging material.

Ancillary Equipment

The relatively low unity capacity of spiral separators (1-5 t/h/start) means that attention to feed distribution and product collection and laundering are key factors in the effective design of process plants utilising spiral separators.

Feed Distributor

The normal installation regime for spiral separators involves the arrangement of multi-start units into banks of up to twelve unit spiral assemblies. Each spiral bank is fed with a distributor. The feed to the total bank reports to the distributor which can be configured as top-entry or bottom-entry. The function of the distributor is to quell the inflow slurry and divide and distribute the slurry equally and homogenously to each of the spiral trough feed points. This function requires a design that ensures wear-resistance to the impact abrasion of the feed slurry and the sliding abrasion of outflow slurries, whilst ensuring that volumetric considerations and internal flow patterns provide for slurry homogeneity and even distribution to the distributor outlets.

Product Launders

The use of product boxes to collect and direct the spiral product fractions from multi-start spiral separators has the added advantage of providing for direct ("engaged") laundering. Open-troughed longitudinal launders can be mounted directly under and around the product box outlets. This system of "engaged" launders eliminates the need for connecting hoses and minimises splash.

Manufacturing Methods / Construction Materials

The system of reverse casting, now well-established for spiral separator manufacture, ensures reproducibility of spiral trough dimensions and frictional flow characteristics through the use of a sprayable polyurethane formulation. The use of structural fibreglass material for the spiral troughs ensures the equipment is relatively light-weight thereby reducing the size and cost of structural support systems required for spiral bank installations. The availability and use of polyurethane castings for various componentry (feed boxes, splitters, repulpers, product boxes) ensures the most appropriate wear-resistant materials are utilised in areas of high abrasion.

SPECIFIC SPIRAL DEVELOPMENTS

Recent developments in spiral separator design are embodied in three models; EP, HC and MG7S.

The EP (Enhanced Performance) Spiral

For the past 10 years, the MG4 model spiral separator and its derivatives (MG4A, MG4B, MG4C, MG5) have been accepted as the benchmark for rougher and scavenger spiral duties. The MG4 model spirals have seven-turns, a diameter of 630mm and share a common trough design. A single auxiliary concentrate splitter is located 4 turns from the top and standard units are supplied with two repulpers.

The EP model spiral separator has been developed to supersede the MG4 family of spiral models. The EP model spiral separator incorporates profile and pitch characteristics similar to MG4 that have been refined, blended and compressed into only six turns.

Physical features that distinguish the EP model spiral separator from its predecessors include; reduced overall height, fewer turbulent zones, reduced wall height giving better access in multi-start assemblies, a deeper concentrate channel and improved "edge-roll" for containing splash at high volumetric flows. Additionally, the EP model is fitted with two re-designed (and patented) repulpers. The repulpers ride on top of the stream and therefore dynamically self-adjust to variations in volumetric flowrate. The repulpers fitted to earlier model spiral separators are fixed and when the volumetric flowrate increased beyond a certain level, their action became too violent and counterproductive. Furthermore, their effectiveness was negated altogether if the flowrate dropped to a level below their influence. The new design allows the repulper to make a more optimal contribution over a wider range of operating conditions. As well as being self-adjusting, the new repulper has an improved action with a well-distributed, fan-like spray. No lids are necessary as the new repulpers are splash free.

The metallurgical performance of the EP model spiral separator has been measured and benchmarked against MG4 and other rougher spiral models. Performance testing has focused on a variety of mineral sand feed types.

Performance Data

The data plotted in Figure 1 pertain to testwork conducted on a mineral sand sample from the USA. The model EP spiral was tested parellel with an MG4C model spiral.

The data (Figure 1) show a clear performance advantage to the EP model spiral separator.

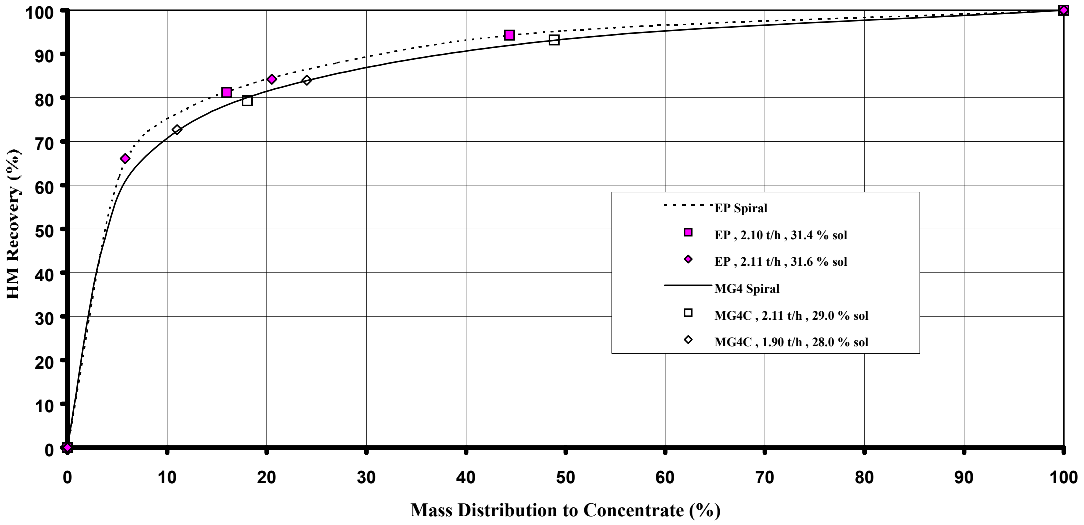

Figure 1. Spiral performance - EP Spiral versus MG4

A further series of six tests was conducted on a sample of mineral sand from South Africa, covering a range of three different feed rate loadings. The summarised data plotted in Figure 2 indicate that, at 15% mass yield to concentrate, the EP spiral recovered 3 to 5% more HM than the MG4B over the range of feed rates tested (1.6 – 2.6 t/h/start). At a mass yield of 30% to concentrate the H. M recovery increased by 5 – 7%.

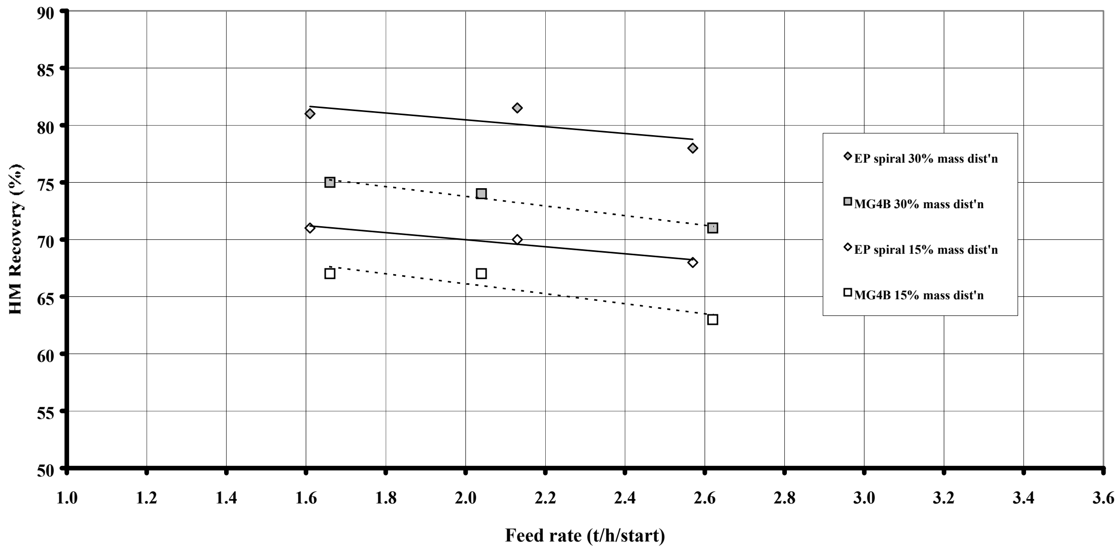

Figure 2. **Spiral performance - Recovery vs feed rate**

High Capacity Spirals

A high capacity mineral spiral (the MG2 model) was introduced in 1977[2].

The MG2 model spiral separator was found to be successful on certain feed types and it has found particular favour in certain mineral sand and tantalum operations. However, its metallurgical performance has proven to be sensitive to feed characteristics.

Subsequent effort was focused on the development of a high capacity spiral separator that was more versatile and physically smaller than the MG2 model. A 6-turn, high capacity prototype was developed with a smaller diameter than the MG2. The geometry allows "quad-start" assembly within the design envelope of cross trough slopes, down-trough slopes and profile variations. This quad-start configuration provides an additional 33% capacity over the 3-start spiral configurations in addition to the increases possible due to higher spiral trough loadings.

Derivatives of the new high capacity spiral were produced, each with different pitch, slope and profile characteristics. The three models developed (HC1, HC2 and HC3) all feature a single auxiliary splitter and two new generation repulpers.

Each of the three HC model spiral separators demonstrates individual performance characteristics and therefore each design has been retained to meet particular needs in the field. The HC1 is a spiral model aimed at general application with a tolerance to variations in feed characteristics; particularly mineral assemblage and particle size distribution.

The design of the HC2 model spiral was initiated after it was observed that the slurry velocity on the HC1 was faster than predicted. The pitch and profile design of the HC2 was targeted towards gentler flow behaviour resulting in this model being well suited to finer sized and more difficult to separate feed, albeit at lower loadings.

The HC3 model proved capable of handling very high volumetric and solids feedrate loadings. Higher slurry velocities mean that at low to normal operating loads (4 to 6 t/h/start for HC spirals), the separation efficiency is not as high as its HC1 and HC2 counterparts. However, as the feedrate increases to relatively high levels (7 to 10 t/h/start), the separation efficiency of the HC3 is retained whilst the efficiencies of the HC1 and HC2 spiral separators decline.

Performance data

A comprehensive test program was conducted on mineral sand material from Western Australia, in which the development HC1 spiral separator was tested against the MG4C and the MG2 model spiral separators.

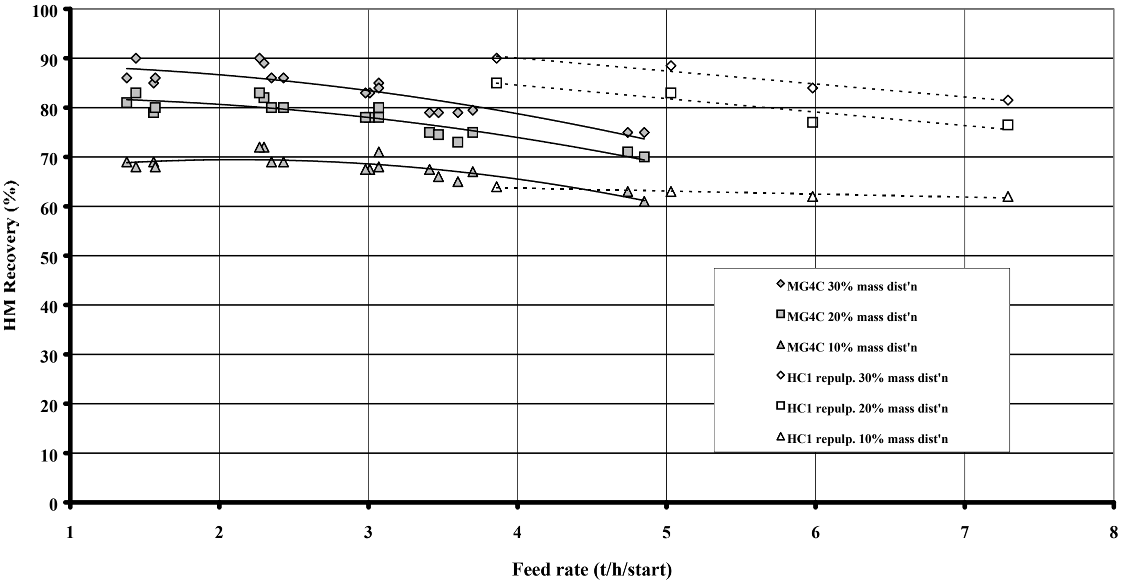

Figure 3. Spiral performance - Recovery vs feed rate (MG4 vs HC1)

The results (Figure 3) indicate that the HC1 achieved equivalent HM recoveries at feed rates approximately twice the rate on the MG4C model spiral separator. Each spiral achieved 90% HM recovery at a 30% mass take to concentrate. This occurred on the MG4C spiral at a feed rate of approximately 2 t/h per start and 4 t/h/start on the HC1 spiral separator.

The relative performance of the HC1 (fitted with and without repulpers) MG2 and MG4C model spirals is illustrated in Figure 4

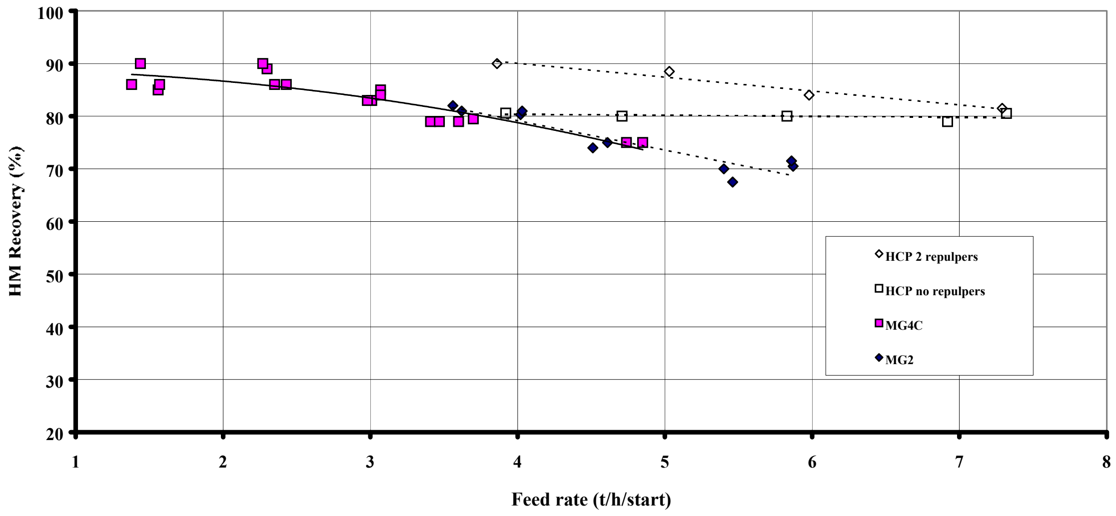

Figure 4. Spiral performance - HM Recovery at 30% mass distribution to concentrate

The data indicate that the HC1 exhibits superior performance to the MG2. Furthermore, the beneficial effects of repulpers on the HC spiral is clearly demonstrated.

Data from a series of tests conducted on a different Western Australian mineral sand are plotted in Figures 5 & 6.

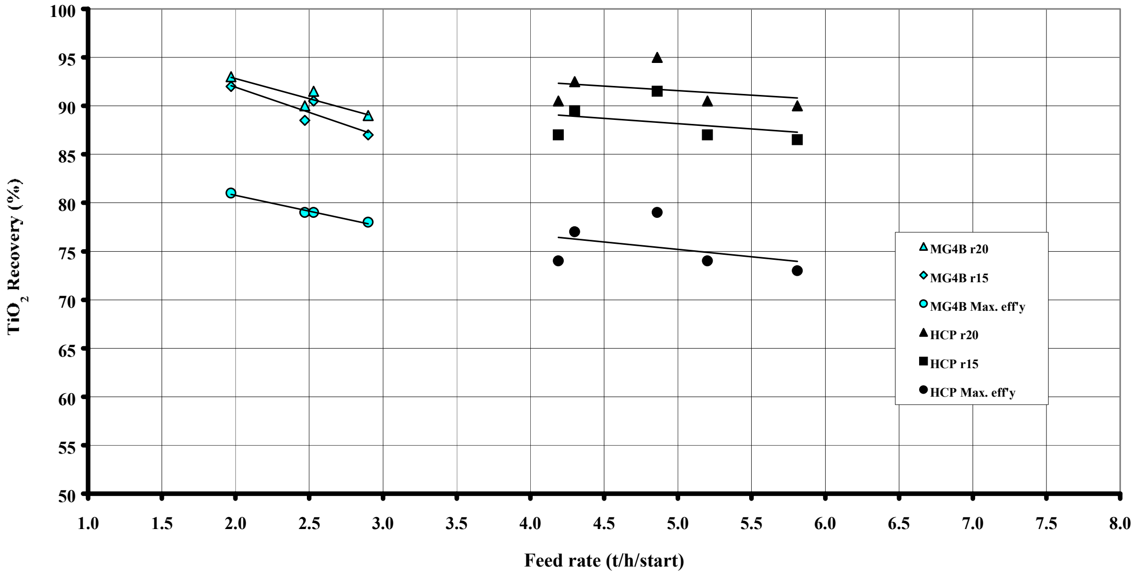

Figure 5. Spiral performance - TiO_2 Recovery vs feed rate

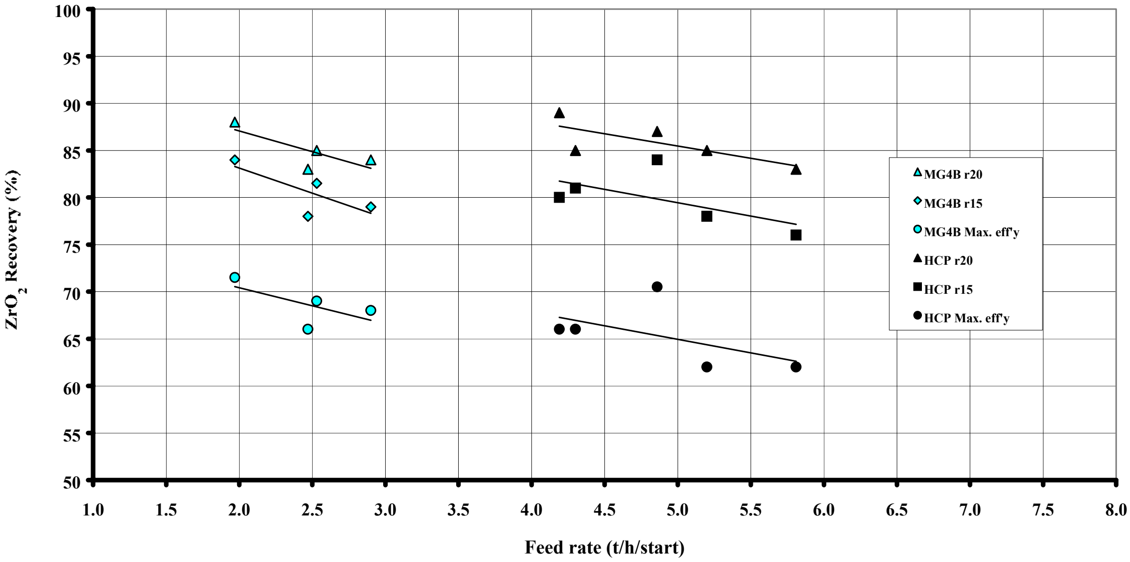

Figure 6. Spiral performance - ZrO_2 Recovery vs feed rate

The data indicate that at 20% mass distribution to concentrate, the MG4B spiral achieved 93% TiO_2 recovery and 87% ZiO_2 recovery, at a feed rate of 2.0 t/h. For the same yield, the HC spiral achieved equivalent performance, at double the feed rate, ie 4.0 t/h.

A series of tests was conducted on an Australian East Coast mineral sand sample in which the performances of an HC2, an HC3 and a standard diameter rougher spiral were compared.

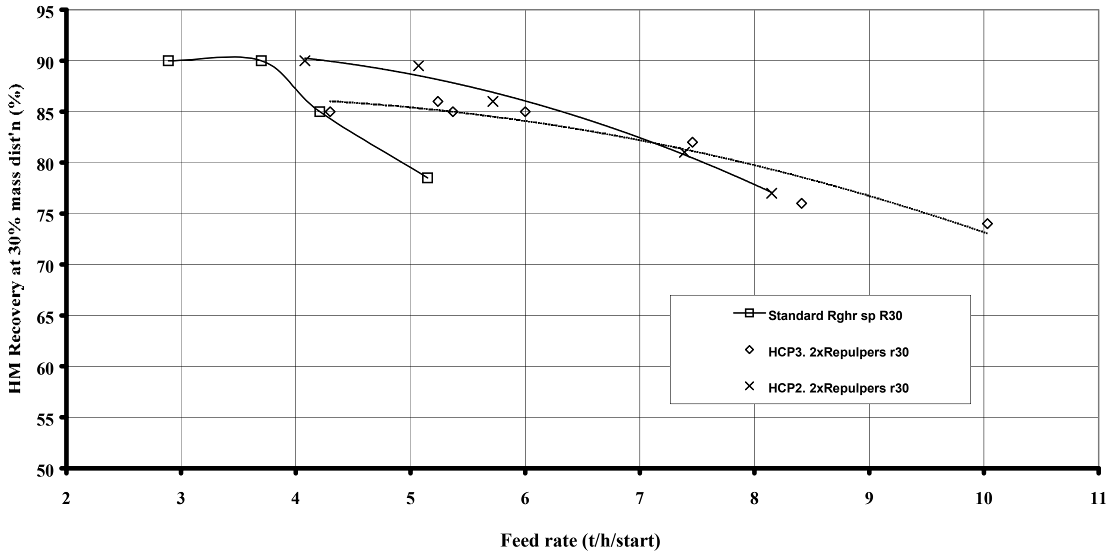

Figure 7. Spiral Performance - Australian East Coast feed

The test results (Figure 7) show favourable performance to the gentler HC2 over the range of 4 to 7 t/h/start. In fact, the HC2 reaches the limit of its feed capacity at 8 t/h. The curves cross at 7 t/h and from 7 to 10 t/h the HC3 is superior.

The Hybrid Medium Grade/Fine Mineral Spiral

A hybrid mineral spiral separator (the MG7S) was developed to meet a duty that called for equivalent metallurgical performance to the MG4 spiral separator whilst providing flow behaviour at the discharge whereby the tailing fraction could be split into two streams:

i) a high-sand / low-water stream; and
ii) a high-water / low-sand stream.

This requirement necessitated a spiral trough design that facilitated the slurry to be slowed and steadied to allow settling of sand particles, whilst maintaining transport of the material. The criterion was to produce a sand tailing of >50% solids pulp density and a water tailing of <6% solids pulp density.

Testwork was conducted on an Australian mineral sand using MG7S and MG4B model spiral separators operating at 3.5t/h start and at equivalent metallurgical performance. Pulp density measurements were taken at four different mass distributions to tailings. The results of these tests are presented in Figure 8.

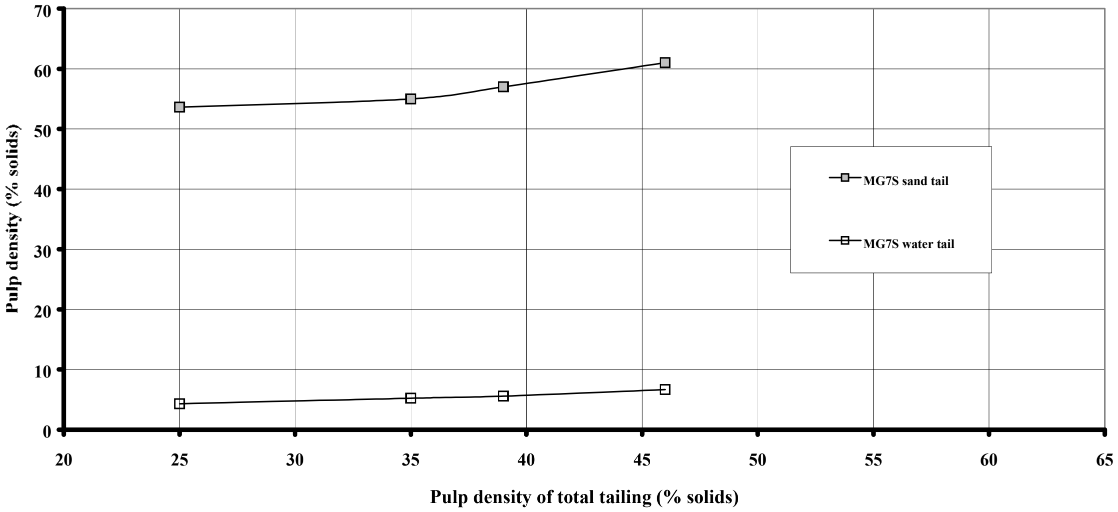

Figure 8. **Spiral performance - Tailing water/sand split**

The data demonstrate that the MG7S spiral separator achieved a solid/fluid spilt that meets the performance targets in three out of the four sets of operating conditions.

FLOWSHEET IMPLICATIONS AND CONCEPTS

The introduction of new spiral separator models and features has generally been driven by the requirement to provide robust gravity flowsheets with the need to process more complex and variable ores. The increasing complexity of ore bodies is related to finer particle sizing (both in terms of the valuable heavy minerals and the relative difference between the grain size of the gangue and the values) and the deportment of near gravity material, which includes non-valuable heavy minerals, altered minerals and composite particulates.

One of the primary objectives in flowsheet design is to provide a circuit that will operate effectively over a range of feed conditions with minimal operator intervention.

The significant improvements to spiral circuit performance by the introduction of the new generation spiral models has resulted from not just the increased separation efficiency but also the stability attributed to the increased tolerance to feed fluctuations and operational changes.

The stability of the performance is indicated by the minimal data scatter found when generating recovery versus yield curves necessary in the development of circuit performance prediction models. Figure 9 shows this feature of spiral separation performance with a MG4CF model spiral separator. The ability of the unit to compensate for varying feed conditions (in this case, varying feed rate) is indicated by all the data points falling on the same separation curve.

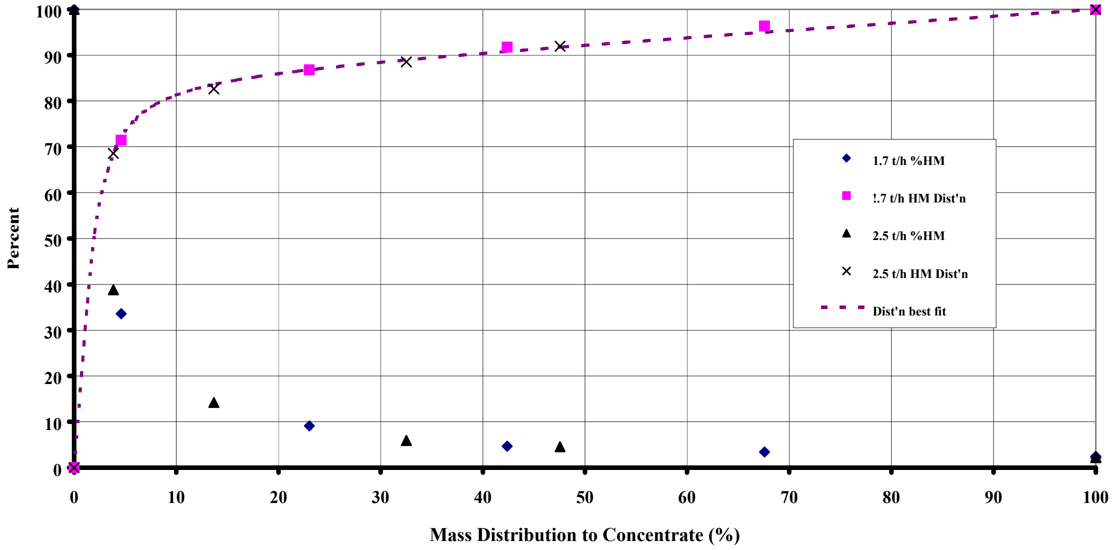

Figure 9. MG4CF Spiral Separator Performance at 1.7 and 2.5 t/h per start

A series of tests was conducted on a MG4CF spiral separator covering a range of feed types to be fed to a primary concentration plant. The tests were conducted at fixed splitter positions in order to determine the level of control necessary to ensure consistent performance over the range of potential feed grades. These data are shown in Figure 10.

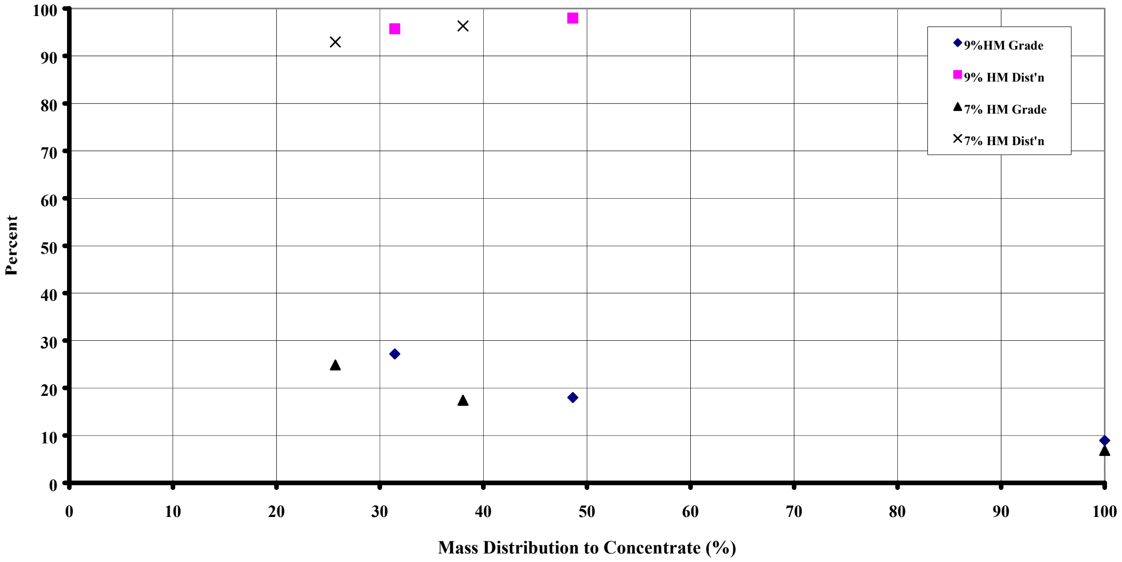

Figure 10. **MG4CF Spiral Separator Performance at 7 and 9%HM Feed**

The concentrate grade achieved for the 7% HM feed was reproduced for a 30% increase in feed grade to 9% HM. More significantly, for the rougher stage in the circuit the recovery of HM to concentrate was >90% for both cases. The separation performance for the 7 and 9% HM feeds was essentially the same. The spiral separator can be seen to automatically compensate for the changes in feed grade, as indicated by the change in yield to the various streams without the need to change the splitter positions. The implication of this, is that under normal operating conditions the rougher spiral splitters in the rougher section of the wet plant should require only minimal, or zero adjustment.

The introduction of more efficient spiral separators has facilitated the rationalisation of wet plant flowsheet design resulting in fewer stages being required. Consequential benefits include reduced inter-stage equipment, (pumps, hoppers and pipework), and lower energy demand. A further advantage is the ability of the circuit to handle significant feed variations.

The high capacity spiral separators offer the option of full rougher (primary stage) tailings scavenging without severe cost penalties. This is particularly relevant for the more difficult to treat or variable orebodies.

The availability of spiral separators fitted with slimes/water splitters has also impacted on process flowsheet designs and the operability of wet gravity circuits. The ability to remove a slime or water split from a spiral separator is not novel[5]. However, in recent spiral separator models the slime/water splitter location and functionality has made the split more definitive and controllable.

The MG7S spiral separator was developed with the further objective that the slimes/water stream would contain minimal solids such that this fraction could report to a slimes thickener without sand solids that would limit the capacity of the thickener. The design profile at the point that the slimes splitter is located on the spiral trough is such that the sand solids settling rate is enhanced; thereby reducing the proportion of these particles reporting to the "water split fraction". The effect on the overall gravity circuit with the use of these model spirals is that a high density sand tailings stream is generated. This stream would be suitable for tailings stacking as high rill angles and reduced pumping costs, whilst simultaneously producing a dilute slime/water stream for thickening. These features contribute to significant operational benefits and cost savings.

CONCLUSION

The wide variety of spiral separator models now available provides a selection of models that ensures most applications where gravity separation of fine minerals can be utilised are well catered for with an efficient low-cost process plant incorporating spiral separators. Further benefits to operators of mineral processing plants incorporating spiral separators include:

- Efficient feed distribution and products laundering systems
- Ease of control
- Low maintenance and long service life
- The availability of circuit modelling systems
- Simplified plant operation

The ongoing development effort to improve the metallurgical performance and capacity of spiral separators for specific duties has effectively extended the product life cycle of this ubiquitous gravity separation device.

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