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GRAVITY SEPARATION: OLD TECHNIQUE/NEW METHODS

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A comparative review of various types of the main gravity separation devices, both in the recent past and present is presented. The application of each device is discussed in turn, with details of the variables involved and the respective advantages and disadvantages of the separators, together with explanatory diagrams illustrating the processes.

Keywords: Gravity concentration; Jig; Spiral; Centrifugal separation; Shaking table; Cone

INTRODUCTION

Gravity separation, which relies on the difference in specific gravities of minerals, is one of the oldest techniques for separating minerals. The method has the attraction of generally low capital and operating costs which together with the lack of chemicals and excessive heating requirements means it is generally environment friendly. Over the last 25 years new gravity separation equipment has enhanced these factors, such that wherever possible gravity separation is a preferred technique. In Australia, where the traditional user is the mineral sands industry, other hard rock minerals such as tantalum and tin are being recovered successfully using gravity separation.

In this article, the following gravity separation methods will be discussed:

- Jigs—conventional, in line pressure and centrifugal
- Pinched sluices—trays and cones
- Spirals—wash water and wash waterless
- Shaking tables—wet and air
- Fine particle separators—Falcon and MGS
- Gravity/sizing—hydrosizers and cyclones

A brief history, followed by the separation principle used precedes an itemised list of the variables, advantages and disadvantages of each separation device. A diagram of the separation action is also given in each case.

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JIGS

Conventional jigs have been in use for well over a century. New developments include the In Line Pressure jig and the Kelsey jig, the latter of which incorporates centrifugal motion.

In principle, separation of particles of differing specific gravity is effected in a bed resting on a ragging screen. The bed is fluidised by a vertical pulsating motion created by a diaphragm and an incoming flow of hutch water, coupled with a bed of intermediate specific gravity particles or "ragging". The pulsating and dilating action of this motion on the bed causes the heavier particles (high specific gravity and size) to sink into and through the ragging to form a concentrate underflow, and lighter and smaller particles to form a tailing overflow (Fig. 1).

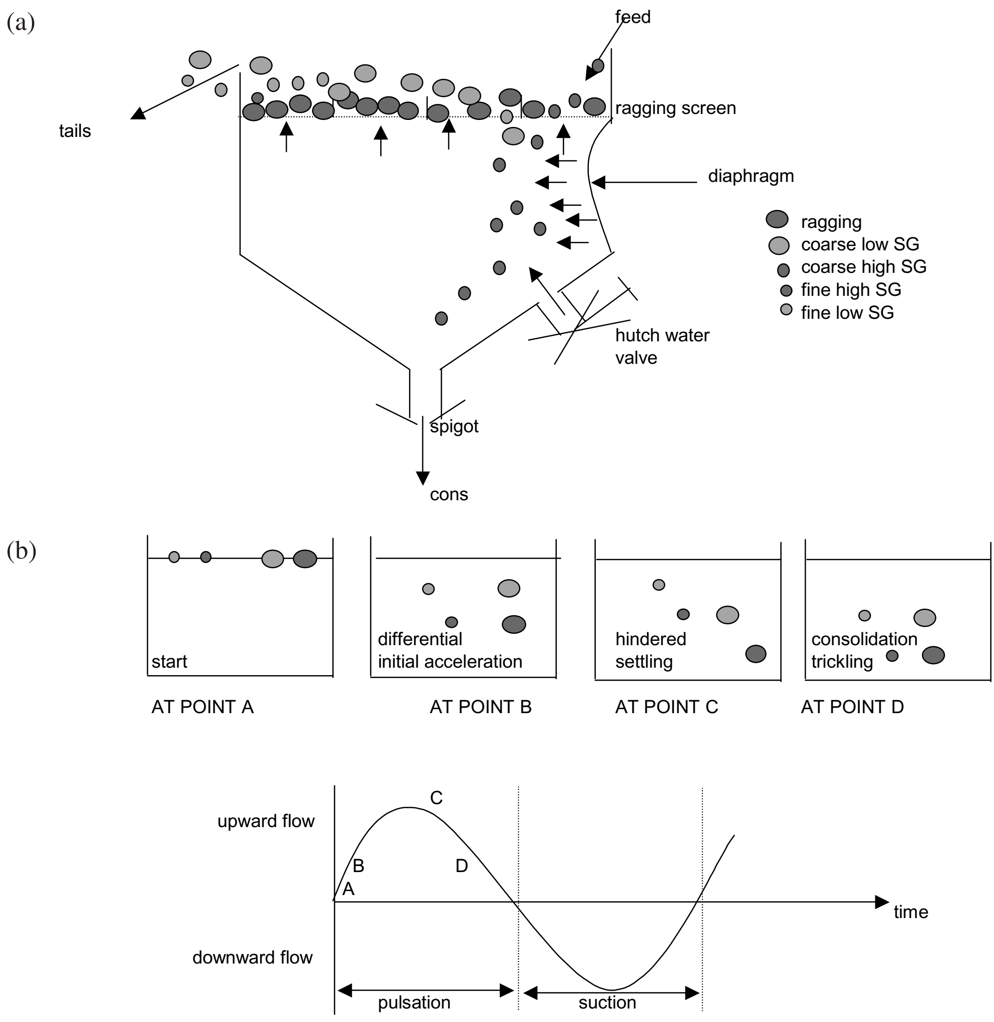


FIGURE 1 (a) Cross section of a typical jig. (b) The jigging cycle.

Conventional Jigs

There are many variations of a conventional jig; one example is the Russell. This consists of two parallel feed boxes each of which discharges into two sets of cells arranged in series. The feed slurry flows over the two hutches where it is subjected to the forces described above. The high specific gravity (SG)/coarse grains pass through the ragging and screens into the hutches where they are removed as an underflow concentrate, while the remainder of slurry discharges into an overflow launder as tailings.

Variables

- Pulse rate (increased rate causes greater bed dilation and concentrate weight take, up to a maximum value, but increases mechanical stress)
- Stroke length (longer stroke increases concentrate weight, but also mechanical stress)
- Hutch water (required to maintain uniform bed fluidisation in conjunction with the above, but will wash fine heavies to tails if excessive)
- Ragging (the type of ragging, its SG, particle size, and shape will have an influence on the separation)
- Bed depth and ragging screen aperture

Advantages

- Able to recover coarse particles, thus reducing grinding requirements for hard rock ores, and excessive slimes generation
- Open visual and physical inspection possible with many adjustments

Disadvantages

- Operation an "art", largely based on experience, and is subjective
- Ragging screen requires periodic cleaning to prevent blinding and build-up of coarse heavies
- Not suitable for recovery of fines
- Use a lot of water

In Line Pressure Jigs

These jigs are a recent Australian development, and work on a similar principle to the conventional jig, except that they operate at a pressure elevated above atmospheric (typically 70 kpa).

Variables

- As per conventional jigs (i.e., pulse rate, stroke length, hutch water, ragging type and size, bed depth)

Advantages

- As per conventional jigs with respect to coarse particle size recovery

– Compact, with small area requirements for capacity
– Can be installed in a circuit with minimal feed and product pumping requirements

Disadvantages

– Similar to conventional jigs with respect to operation being an "art", ragging screen cleaning, fines recovery and water use
– All separation surfaces are enclosed (no visual checks possible)

Centrifugal Jigs

The Kelsey jig, developed in the last 20 years, is the best-known example of a centrifugal jig. The principle of the Kelsey jig is similar to the conventional jigs in terms of the pulsing motion of the bed and the use of ragging to achieve a separation, but is aided by the use of a centrifugal "*G*" force, which increases the sensitivity of the separation allowing finer and more similar SG particles to be separated (Fig. 2).

Variables

– Rotational speed or spin (increased spin compresses the bed and the *G* force, increasing concentrate grade and reducing weight)
– Pulse/hutch water/stroke length/ragging type and size (all have similar effects as with the conventional jigs)

Advantages

– Able to separate much finer particles (typically to 38 microns) with lower SG differentials (e.g., zircon SG 4.4 and kyanite SG 3.2)
– Reasonable capacity (especially new larger model) for the size of feed material

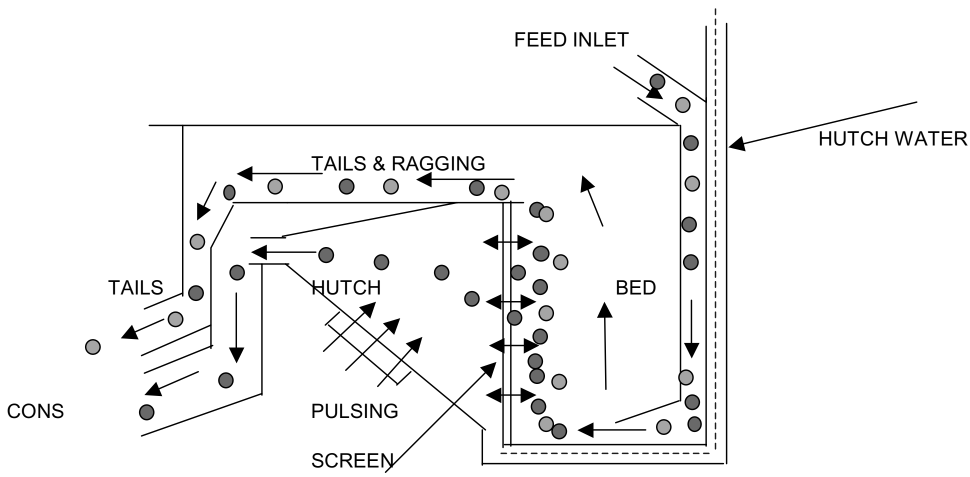


FIGURE 2 Partial cross section of a Kelsey jig.

Disadvantages

– Mechanically complex, requiring daily checking and greasing, and periodic overhaul
– Essential to screen feed below that of internal screen to prevent blinding, and screen tailings to recover ragging
– Essential to clean internal screen on a daily basis, although this can now be done automatically
– Requires solid foundations and ancillary screening equipment, so coupled with the jig itself is relatively expensive (capital and operating)

PINCHED SLUICES

Pinched sluice type gravity separators were popular in the 1960s and 70s, primarily in the Australian minerals sands industry, until the advent of the new generation of spirals.

The pinched sluice is basically an inclined slope, over which a slurry containing particles of different SG flows. Due to the gravitational and frictional forces occurring, and a narrowing of the sluicing deck (pinching), segregation occurs with the finer heavier particles migrating to the bottom of the flowing film and the lighter coarser to the top. By means of a slot (concentrate off-take) near the end of sluice the fine heavy particles are removed from the main tailings stream, which passes over the slot and discharges at the end (Fig. 3).

There are (or were) two types of pinched sluice.

Trays

There were several variations of trays, which were the first pinched sluice devices. Wright trays and York trays were typical examples. They normally consisted of multiple feed points per unit, with several stages (e.g., rougher/cleaner/scavenger) in each unit.

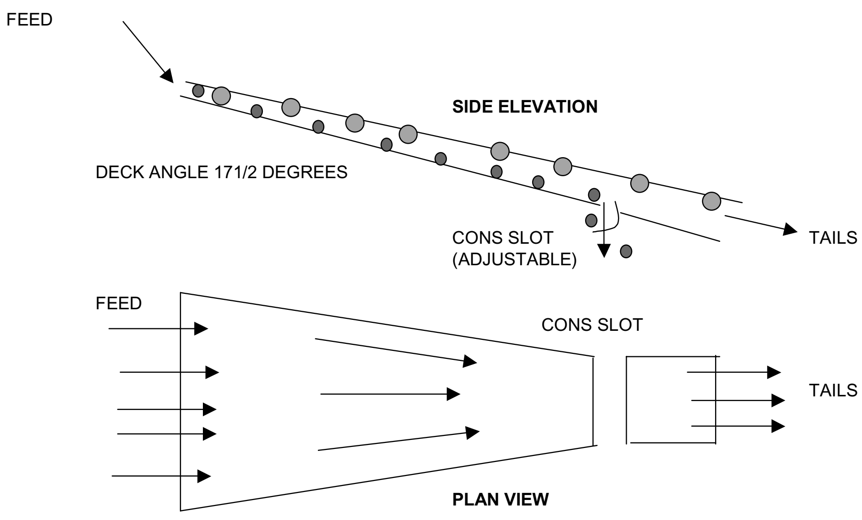


FIGURE 3 Action of separation in a pinched sluice.

Advantages

– Open for visual inspection, adjustment and cleaning
– High feed density (63% solids) so low volume-pumping requirement

Disadvantages

– Large space requirement and unwieldy
– Low upgrade ratio (typically 3 to 1)
– Controlled feed density necessary
– Low recovery of fines
– Feed requires screening
– Low tolerance of slimes
– Multiple feed points and separating surfaces
– Require wash water for density control on cleaner stages

Cones

Cones, or Reichert Cones, are essentially an improved version of the tray, which as the name suggests, are cone-shaped with a central single feed point. Generally they contain multiple stages mounted vertically above each other (Fig. 4). The more common configurations include the 4DS (four double/single stages) and 2DSS.DS (two double/single/single stages plus a double/single), the former used as roughers and the latter as cleaners.

Variables

– Feed rate (increased rate reduces performance above an optimum – typically 70 tph for a standard cone)

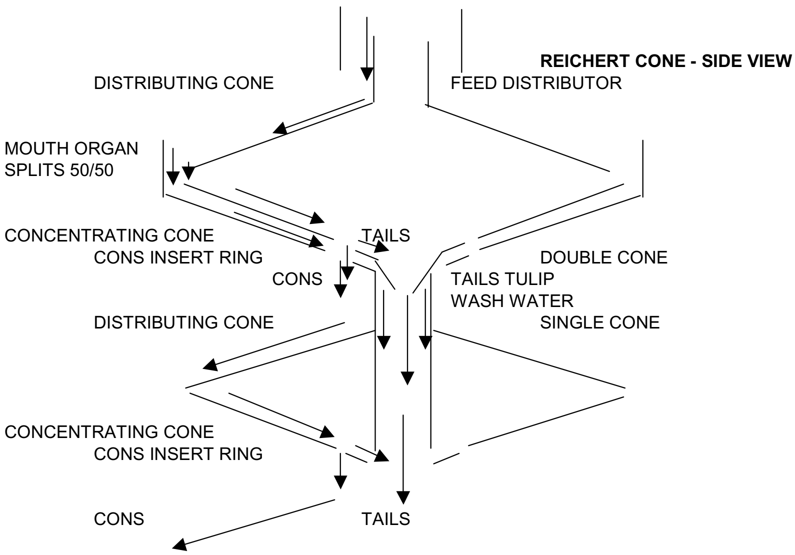


FIGURE 4 Side view of action in a Reichert Cone.

– Feed density (needs to be kept between 60–63% solids otherwise recovery or grade will suffer)
– Insert settings (range 1 to 9 with increasing opening greater recovery/lower grade)

Advantages

– High capacity for floor area (particularly the later 3 metre cones)
– High feed density (63% solids) so low volume-pumping requirement

Disadvantages

– Low upgrade ratio (typically 3 to 1)
– Controlled feed density necessary
– Low recovery of fines
– Feed requires screening
– Low tolerance of slimes
– Bottom separating surfaces of cones not visible or easily accessible
– Requires wash water to maintain density on cleaner stages

SPIRALS

The early models of spirals, in use prior to the development of trays and cones, were usually made of cast iron or even rubber tyres and usually required wash water. In the early 1980s, a new generation of spirals made of fibreglass and polyurethane, with modified profiles and concentrate cutters that eliminated the need for wash water, were developed.

The spiral is basically an inclined chute with a complex cross section (Fig. 5(a)) wrapped around a central column. The principle is that a combination of gravitational and centrifugal forces acting upon particles of differing specific gravities cause fine heavies and coarse lights to segregate (Fig. 5(b)). These forces are greater than in the cone and, coupled with the lower slurry density normally used, produce a greater upgrade ratio than the pinched sluice (typically 5 to 1) and a better recovery of fines.

Wash Waterless Spirals

The use of wash waterless spirals is normally on rougher and scavenger stages, although cleaner stages can also use this type of spiral.

Variables

– Feed rate (as feed rate increases performance falls, however there is generally an optimum)
– Feed density (as density increases performance also falls, although very fine particles tend to be recovered better)
– Splitter settings (wider cuts increase concentrate recovery but reduce grade)
– Feed sizing (optimum feed sizing is $-3\,\text{mm} + 75\,\mu$)

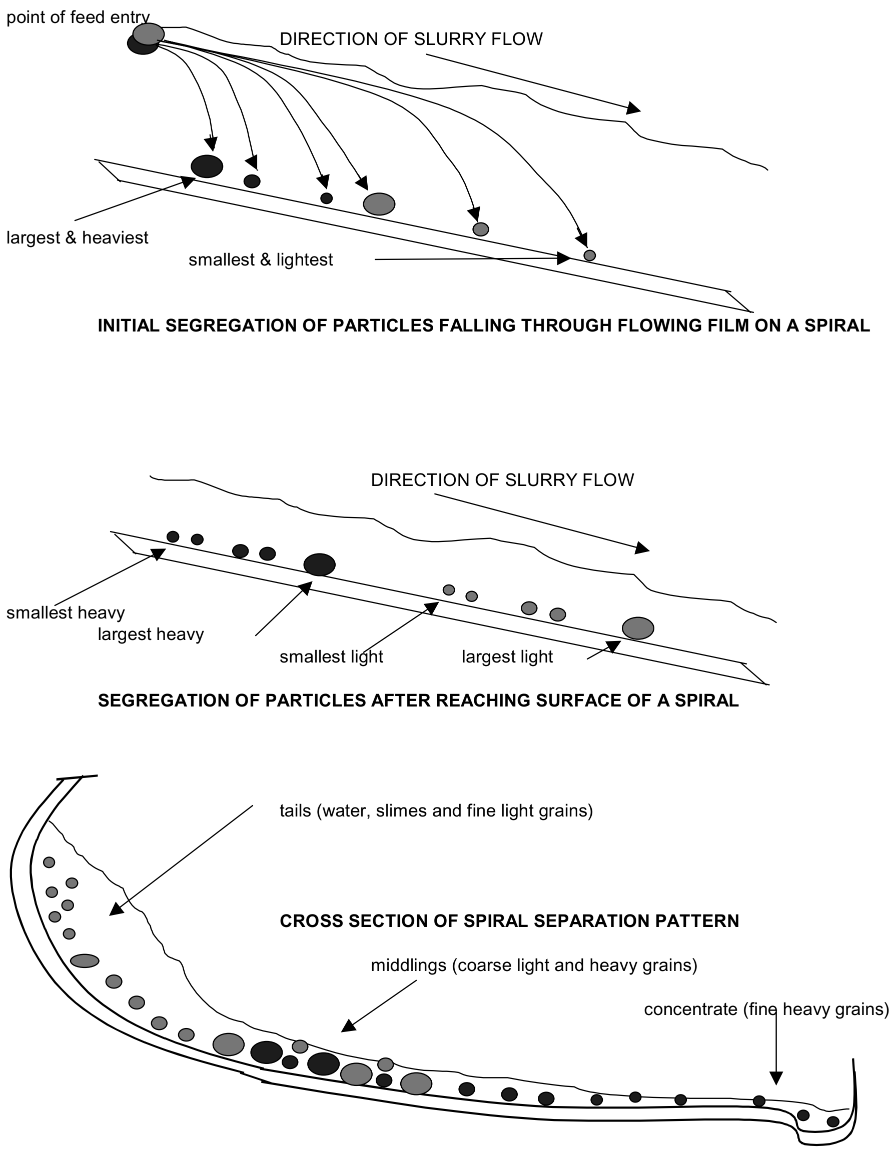


FIGURE 5 Action in a typical spiral.

Advantages

- Open for visual inspection, adjustment and cleaning
- High upgrade ratio means fewer stages in circuit, smaller cleaning capacity, and throwaway rougher tails in some cases
- Able to tolerate moderate to large variations in slurry feed density
- High capacity for floor area when used as triple starts, or with large diameters
- Better slimes and oversize tolerance
- No wash water

Disadvantages

– Multiple feed points require even distribution

Wash Water Spirals

Wash water spirals are normally used only on cleaning stages.

Variables

– As per wash waterless spirals
– Flow of wash water (increased flow produces cleaner concentrate)

Advantages

– Able to produce clean slime-free concentrate
– Other advantages as per wash waterless (except for wash water requirement)

Disadvantages

– Require wash water
– Multiple feed points require good distribution

SHAKING TABLES

The shaking table is another gravity separation device that has been in use for many years. Little has changed in the design, although multi-deck (up to three levels) tables have led to capacity increases relative to floor area. Shaking tables are normally used only on cleaning stages because of their low capacity.

The principle of separation is the motion of particles according to SG and size moving in a slurry (in the case of wet tables) across an inclined table, which oscillates backwards and forwards essentially at right angles to the slope, in conjunction with riffles which hold back the particles which are closest to the deck. This motion and configuration causes the fine high SG particles to migrate closest to the deck and be carried along by the riffles to discharge uppermost from the table, while the low SG coarser particles move or remain closer to the surface of the slurry and ride over the riffles, discharging over the lowest edge of the table. (Fig. 6)

In the case of air tables, as the name suggests, the feed and separation are dry, with the moving bed of particles being fluidised by low pressure air being blown through a canvas deck, which together with deck slope, absence of riffles and the oscillating motion of the table causes fine light SG particles to move to the top of the bed and coarser high SG particles to move closest to the deck, the latter discharging off the lowest part of the table.

Wet Tables

There are various types of wet tables including the Deister, Holman, and Wilfley that are built to handle either coarse or fine feeds.

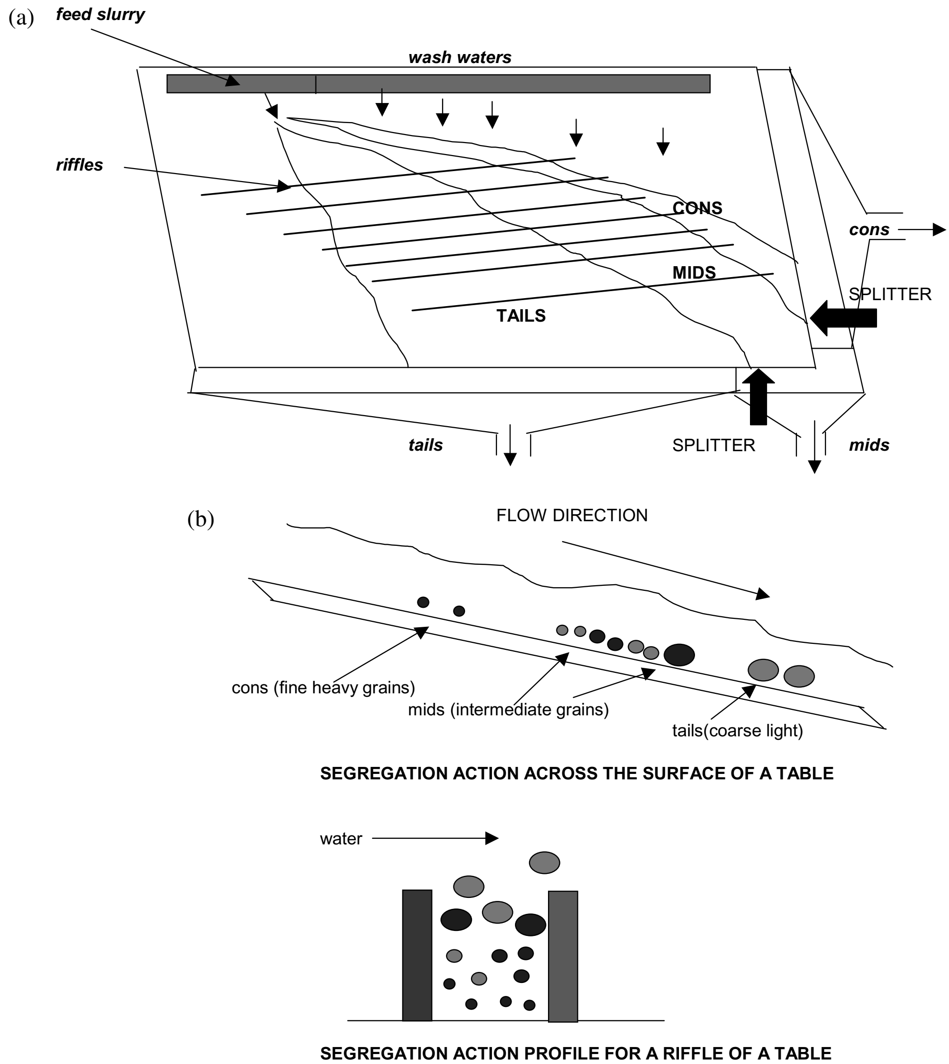


FIGURE 6 The shaking table: (a) plan view; (b) action behind the riffles.

Variables

- Angle of deck (steeper angle less weight to concentrate)
- Length of stroke (longer the stroke, the more the sideways motion and hence more weight to concentrate up to a maximum)
- Frequency of stroke (similar to length i.e., the more frequent the more sideways motion up to a maximum)
- Splitter positions (the position of the splitters on the concentrate launder will determine the weight take to concentrate)
- Feed rate and density (above a maximum of typically 2 tph per full size table and density typically 40% solids, depending on the type and particle size of the feed) separation will be reduced

– Wash water (wash water is added along the top of the table to assist solids flow, maintain low solids density, preventing "dry spots", and washing slimes to tails
– Riffle height (a low riffle height will be better for fine feeds and vice versa)

Advantages

– Highly selective, with high upgrading ratio if used correctly
– Able to see separation and make adjustments

Disadvantages

– Low capacity, large floor area requirements
– Require frequent operator attention, checking and adjustment
– Feed should be sized

Air Tables

Air tables for mineral processing were developed from the grain industry, and are usually adapted for specific uses where dry gravity separation is preferred over other methods. Typically this would be in the cleaning stages of a dry mill such as removal of fine silica from a zircon product.

Variables

– As per wet tables (deck slope, stroke length, stroke frequency, splitters)
– Fluidising air flow (increased flow maintains bed mobility up to a maximum)

Advantages

– Where the process before or after is dry, air tables eliminate the need for additional thermal drying
– Highly selective

Disadvantages

– Low capacity, large floor area required
– Even more frequent operator attention required than wet tables (regular brushing the decks to prevent blinding, splitter adjustment)
– Noisy and dusty (require dust control systems)

FINE PARTICLE SEPARATORS

The greater use of gravity circuits and the need to recovery finer particles have led to the development of specific devices to recover particles generally too fine to recover efficiently using spirals etc.

Two examples are the Falcon Concentrator and the Mozley Multi-Gravity Separator (MGS), although the Kelsey jigs also tend to fall into this category in some respects.

Falcon Concentrator

This machine is basically a combination of a sluice and a continuously operating centrifuge. Capable of operating at a high speed of rotation and hence "*g*" force, it enables fine particles of different SG to be separated.

The shape of the spinning bowl is such that as the feed slurry moves up the bowl the heavier particles react more than the lighter particles to the forces acting upon them. This results in migration of the heavier particles within the slurry stream to the surface in contact with the bowl, while the lighter particles tend to move to the top of the slurry with the water. Separation then takes place by removal of the lower (higher SG) portion of the slurry through a collection lip/slot, the flow through which is regulated by a number of orifices which open and close in a controlled manner, removing the concentrate from the main stream, which discharges to tails (Fig. 7).

Variables

- Speed of rotation or spin (increased spin raises *G* force increasing the separation force on the feed)
- Pulse frequency of concentrate orifices (increased frequency to a maximum will increase weight take)
- Feed rate and density (increased rate and density above a certain maximum will hinder separation)

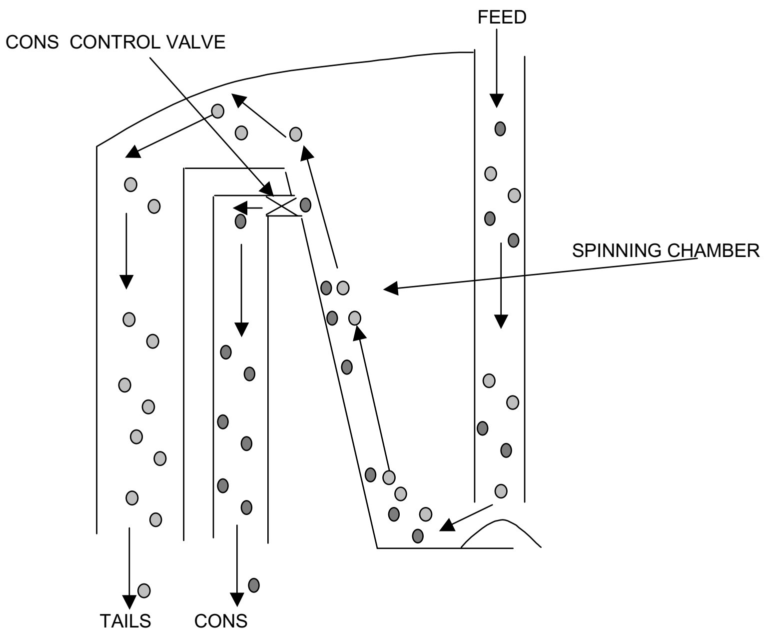


FIGURE 7 Partial cross section of a Falcon continuous separator.

Advantages

– Able to treat particles in size down to 15–20 microns
– Relatively simple mechanically and robust
– Relatively high capacity
– Relatively low operator attention

Disadvantages

– Generally low upgrading ratio (typically 2 to 1)
– Unable to see separating surfaces
– Requires feed to be screened to less than opening size of concentrate orifices to prevent blinding

Multi-Gravity Separator (MGS)

The MGS combines the centrifugal motion of an angled rotating drum (though not at such a high speed) of a Kelsey jig or Falcon Concentrator, with the oscillating motion of a shaking table, to provide an enhanced gravity separation, particularly suited to fine particles.

The principle of the separation in the MGS is based upon the above-mentioned forces that act on particles in a slurry stream being fed and are distributed onto the inside of the drum's surface. With the aid of scrapers and wash water, the high SG particles migrate up the drum to discharge over the drum's top lip, while the low SG particles flow in the opposite direction and discharge over the lower drum lip (Fig. 8).

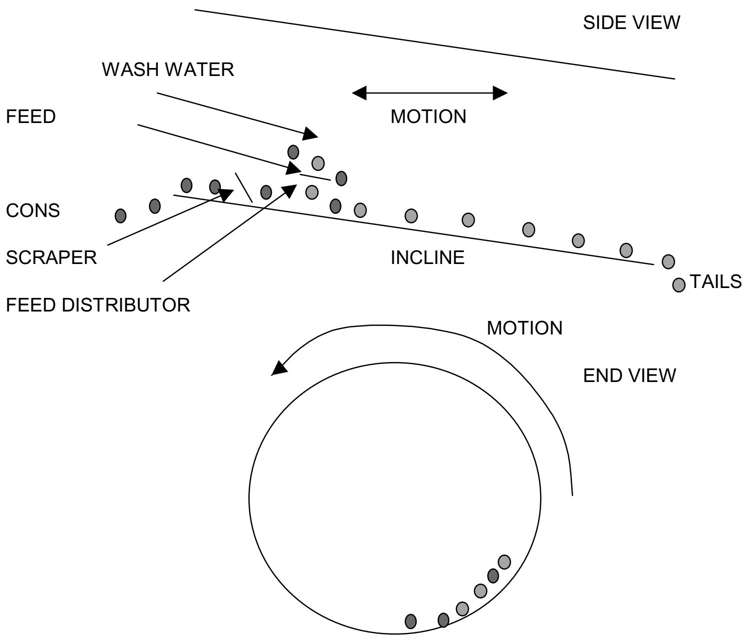


FIGURE 8 Action in a Mozley MGS.

Variables

– Drum rotational speed or spin (increased spin enhances the centrifugal *G* force imparted to the particles, making it more difficult for the particles to move up the drum, hence resulting in a smaller weight take and a cleaner concentrate
– Drum stroke length and frequency (increased length and frequency within limits will tend to increase the forces moving the particles up the drum, resulting in a greater weight take and a lower grade of concentrate)
– Drum wash water will increase the washing of the slurry particles as they try to move up the drum, thus producing a cleaner concentrate
– Drum tilt angle (increased tilt will produce a cleaner concentrate)

Advantages

– Very selective separation with fine-sized particles (typically $-75+10$ microns)
– High upgrading ratios (typically 20 to 1)

Disadvantages

– Low capacity for surface area and space, although larger capacity (and physically bigger) machines are now available
– Mechanically quite complex and expensive
– Generally enclosed so unable to see separation surfaces
– Requires reasonable amount of operator attention
– Unsuited for treating coarse material (feed must be screened)

GRAVITY/SIZING SEPARATORS

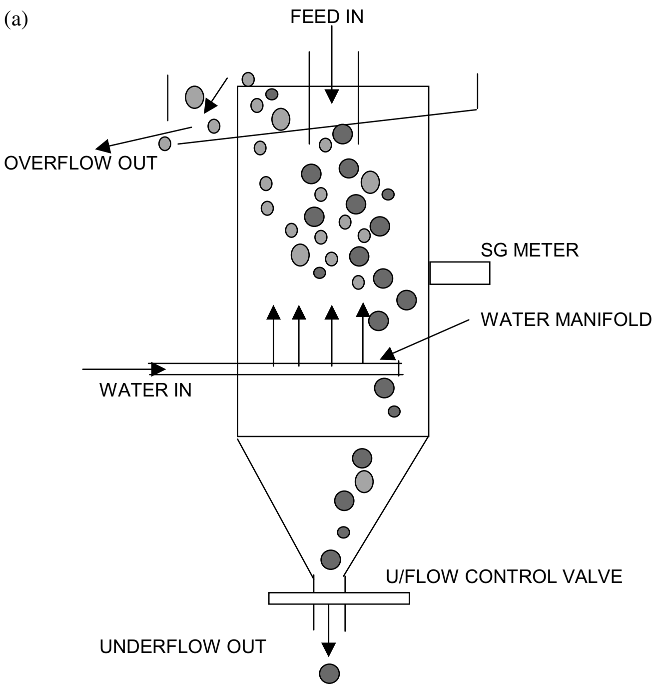
The following two examples of separators are more sizing devices than gravity separators, however because of their nature they also combine particle SG with particle size in their separation.

Hydrosizers

Hydrosizers are a development of the teeter column classifiers that use the principle of particle settling to achieve a separation between fine/light particles and coarse/heavy particles in an environment of a rising flow of water in a tank generated by injection water through a manifold about two thirds of the way down the tank, which creates an overflow of the former, and an underflow of the latter.

A particle of sufficient weight due to its SG and size will settle faster in a fluid than a particle of lower SG and size. If there is a rising up-current of fluid then at a certain volumetric rate the up-current velocity will exceed the settling velocity of the lighter/smaller particles but not that of the heavier/coarser particles and a separation will take place (Fig. 9(a)).

(a)



(b)

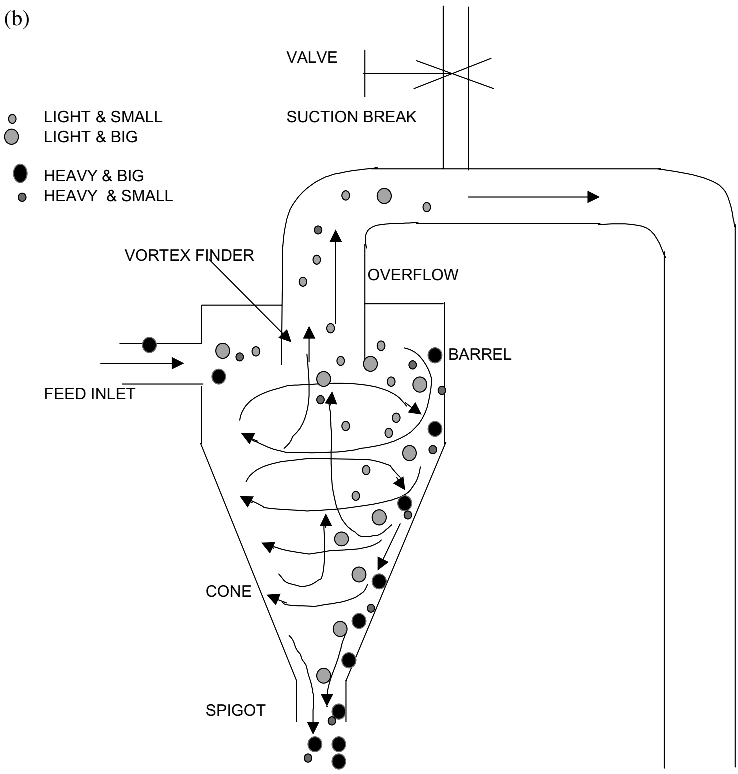


FIGURE 9 (a) Hydrosizer; (b) hydrocyclone.

Variables

- Injection water flow rate (increasing water flow rate will increase the weight of particles (and SG/size) of particles reporting to overflow
- Column density (increasing the SG of the slurry contained in the column between the injection water manifold and the overflow weir will increase the weight to overflow)
- Underflow discharge (increasing the underflow discharge volume rate will reduce the solids density of the column and tend to reduce the upward flow, thus reducing the SG/size of the overflow solids)
- Mass flow rate of feed (increased feed rate above an optimum level will reduce the sharpness of separation)

Advantages

- Precise automatic control of the separation based on SG measurement of the column head in a control loop with the underflow valve
- Able to observe both products and make easy adjustments to control mechanism if required
- No moving parts
- Can be wet or dry fed

Disadvantages

- Require dedicated injection water pump that can deliver a clean, constant but adjustable supply
- Large water requirement
- Large volume for given capacity required (relative to hydrocyclones)
- Require steady feed rate

Hydrocyclones

Hydrocyclones create a separation between coarse/high SG particles and fine/low SG particles based on their geometry and the centrifugal motion of the flow inside them acting on the particles accordingly.

When a slurry is fed under pressure tangentially into the pipe-shaped body of a cyclone, the centrifugal force will tend to throw the heavier particles towards the outside in preference to the lighter ones. The outer particles then move down the cone under pressure and are forced out of the underflow spigot, while the lighter particles (and water) on the inside of the vortex rise up into the vortex finder and discharge as an overflow (Fig. 9(b)).

Variables

- Feed pressure (this is the driving force behind the separation, such that the greater the pressure, the finer the size separation achieved)

– Vortex finder diameter (the greater the diameter, the larger the overflow and the lower the pressure, hence the separation will be coarser)
– Spigot diameter (likewise, the greater the diameter, the larger the flow so the underflow will be finer or wetter); variable spigots can be used
– Siphoning (if the overflow discharges lower relative to the underflow a siphon effect will occur causing increased solids and flow to overflow; this is overcome by introducing a vacuum break)
– Feed density (if the density is too high: typically above 35% solids then separation will be affected)
– Angle and length of the cone section (increased length and shallower angle will reduce the cut size)
– Barrel diameter (the larger the diameter, the greater the capacity, the lower the pressure and the coarser the cut size)

Advantages

– High capacity for the volume and floor area required
– No moving parts
– Limited operator attention

Disadvantages

– Not easily adjustable for changing feed and product requirements
– Need to be fed under pressure and at a steady rate

CONCLUSIONS

The foregoing has been described and compared in simplified terms, the principles, variables, advantages and disadvantages of the majority of the gravity separation devices that are available today, all of which the author has had personal and practical experience with in both production and development environments.

In all cases feed presentation, particularly sizing due to the cross-over effect of fine/heavy and coarse/light is an essential consideration for efficient separation. Another important consideration is to ensure (particularly for hard rock ores) that the minerals are liberated. Selection of the correct separation device for the particular application should always be preceded by test work, while optimisation of the separation in the production situation requires plant surveying under differing parameters.

Acknowledgement

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Andrew Falconer graduated from the University of Birmingham in 1973 with a BSc (Hons) in Minerals Engineering, and subsequently obtained a Master of Mineral Technology degree from Otago University.

He has over 25 years of experience spent mainly in the titanium and tantalum mining industries including wet and dry plants, and has worked on both coasts of Australia and in several African countries.

Andrew has been involved in many varied operational and development roles including plant commissioning, plant management, day-to-day plant metallurgical operations, plant audits, equipment evaluations, pilot plant investigations, process training, client test work etc. Particular areas of expertise include gravity separation, magnetic separation, and electrostatic separation.