TIN ORES
SOME ASPECTS OF PROCESS METALLURGY

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TIN OCCURRENCE

Tin is found in many mineral forms but the only one of economic importance is Cassiterite (SnO_2) and is found in Primary deposits, typically associated with granite intrusive rocks formed from molten rock, (magma), beneath the earth's surface. Cassiterite can occur disseminated in the surrounding rocks or in veins, also with silicates and sulphides as Skarn, and in carbonate beds deposited from fluids containing tin from the magma.

Secondary deposits are known as Alluvial or Placer have stemmed from primary deposits through weathering and erosion by wind and water. Cassiterite being a chemically resistant, heavy oxide mineral concentrates easily under flow conditions in a natural drainage system, as do other heavy minerals present in the primary deposit or picked up on the way through drainage channels. Deposition by this means has formed important sources of tin on land and off-shore in submerged river beds, such as those found in South East Asia; currently Indonesia is the tin major producer in the region.

RECOVERY

In the treatment of copper sulphide ores, recoveries in the mid 90 `s into a saleable copper concentrate grade can be achieved through crush-grind-and froth flotation processes as the flotation collectors available are very selective to the copper mineral and over a wide particle size range.

Such an approach is not possible in the case of hard rock tin ores where the main economic mineral is Cassiterite, Tin Oxide, SnO_2, as the flotation collectors currently available are not selective and only work in a narrow fine particle size range and rarely make a concentrate grade acceptable to smelters ---- which is around 50% Sn minimum.

The main recovery method for cassiterite is based on the difference in Specific Gravity between cassiterite (SG 7.0) and the gangue minerals. Gravity concentration has been practised since Ancient times for Alluvial and Hard rock Deposits, a better method has not been found yet.

HARD ROCK ORES

Below are some tin ores which may be described as “Complex” or “Simple” based on grain size of the cassiterite and dissemination through the mineral suite, ease of liberation through the crushing and grinding circuits, and content of other heavy minerals present particularly Sulphides and Iron Oxides.

Complex

Renison, Cleveland, Queen Hill, St Dizier, Mt Lindsay, Tasmania,

Gillian, Mt Garnet, Queensland, Wheal Jane, Cornwall, Kasbah, Morocco, and Syrymbet Kazakhstan

Simple

Collingwood Qld, South Crofty UK, and Huanuni, Bolivia,

Simple and Low Grade

Taronga, NSW, Gottesberg, Germany and East Kemptville, Canada

Simple and High Grade

San Rafael Peru and deposits in the Congo, Rwanda, Uganda and Tanzania

PROCESS GUIDELINES

General Rules of Thumb for Beneficiation

Pre-concentrate if ore is amenable - Ore Sorter / HMS / Jigs/ Magnets.

Stage Crush and Grind - and do not overgrind by removing liberated cassiterite from the Primary Grinding Circuit as early as possible, by screening. Further liberation is achieved by regrinding gravity plant middling's.

Recover as much as possible by Natural Gravity using Jigs, Spirals and tables

Use tin flotation as a Scavenger on the Gravity plant

Jigs can recover very coarse cassiterite and down to ~ 200 microns Spirals and Tables size range is ~800 microns down to 40 microns and flotation 50 microns to 6 microns Flotation – i.e., there is a size recovery overlap so no particle size gap in the process flow sheet.

PRE-CONCENTRATION METHODS

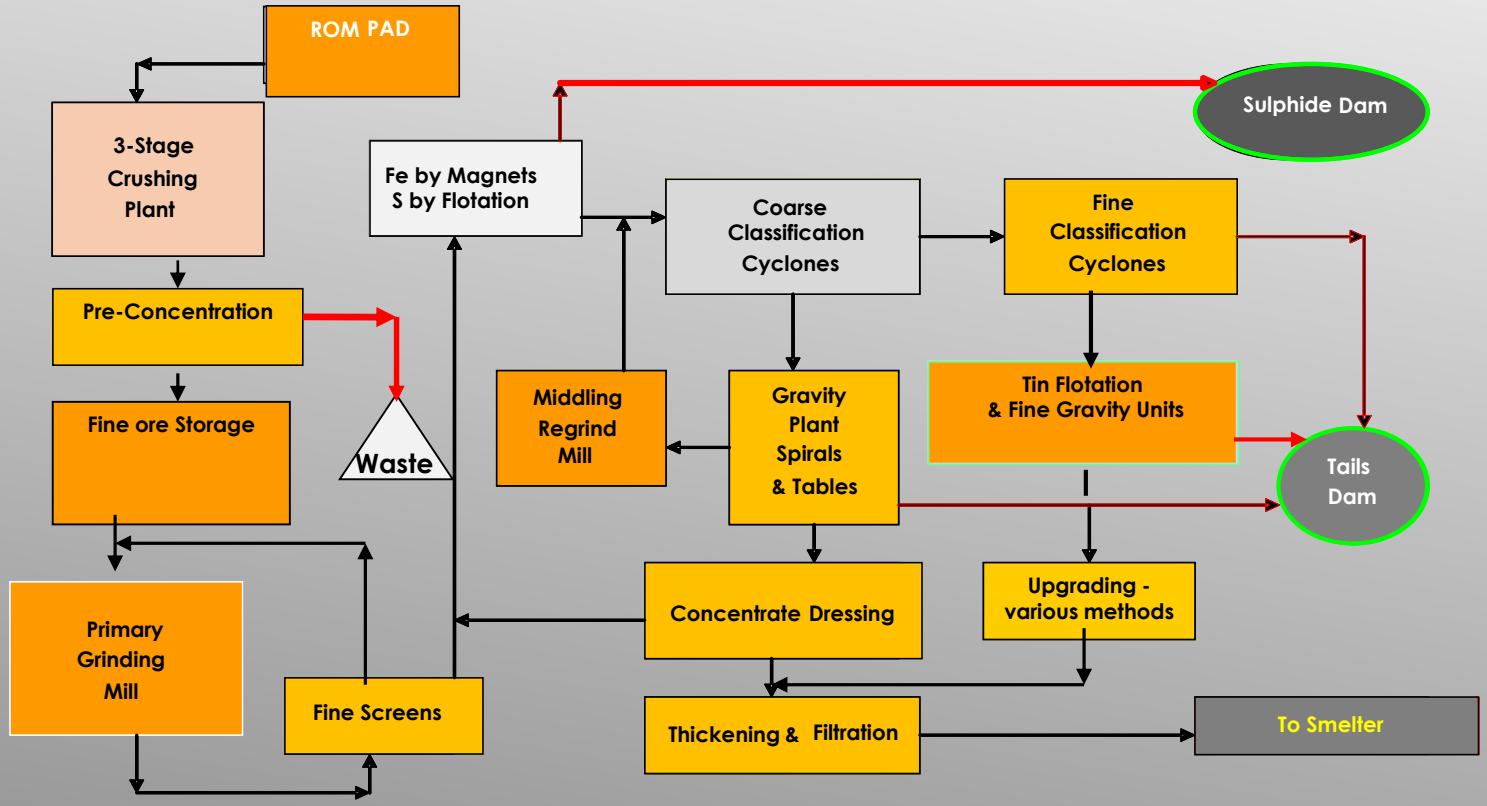
Sensor Ore Sorting has recently been installed in Tungsten Plants to remove barren material at very coarse sizes, and is being tested for a number of tin ores currently. The technology has improved considerably since it was first used for Diamond sorting.

Heavy Media Separation HMS - a very useful tool can separate from coarse sizes down to 0.5mm

The GEKKO Jig, made in Ballarat, is a composition of all the better ideas in jigging in the last 30 years …. Principally by the simple idea of using hydraulics - to pulse the jig bed rather than expensive pressurized water under the bed. . The water consumption is much reduced. The GEKKO is designed to be operated by full instrumentation and jig parameters can be monitored remotely.

These are in use at San Rafael Mine in Peru and are being tested for deposits in the Congo.

Typical flowsheet for hard rock ores:-



HARD ROCK CIRCUITS

LOSS POINTS

At every upgrading step tin loss will occur

See Red Arrows in flowsheet above

Pre-concentration - Rejects -- may have micro-fine tin, which can be assayed but not recovered.

Sulphide or Magnetic conc – in composite, entrained or as another tin mineral such as Stannite Cu_2FeSnS_4

Gravity tail – in composites

Slimes – below 6 micron cassiterite, with siliceous and clay slimes, metal ions and salts from oxidation – all interfere with flotation and have to be removed ahead of flotation

Tin Float tail –still in composite

OPTIMISATION

Nothing can be done about the ore body, it is what it is, but it is now possible to get the best out of it due to Equipment Improvement, New Technology, and Process Control Systems introduced over the past 30 years.

In addition there are tools such as the Scanning Electron Microscope (SEM) to examine minerals in great detail and help determine the best process route during metallurgical testing.

Pre-concentration - *Why Pre-concentrate?*

If ores are amenable to pre-concentration at coarse sizes, an opportunity presents to reject a portion of the crushed ore between the crushing and grinding circuits as a barren fraction which means the size of all downstream processes will be reduced, or conversely, the overall treatment rate can be increased.

For low grade ores it is a key factor in the economics and the practical design of the Process plant which has tonnage limitations – due to the main upgrading unit being low capacity shaking tables although spirals have ameliorated this.

EQUIPMENT DEVELOPMENT

Development work on **Spirals** has focused on the Geometry- Diameter, Pitch and Profile, and Materials of Construction which has gone from in the 1940`s Truck tyres, to cast iron, fibre glass rubber and polyurethane lined.

"All Polyurethane" Spirals are now being made in China using German PU.

These could be a candidate for manufacture by **3D printing** in the near future!

Shaking Tables are still a very important upgrading tool, but have low capacity and occupy a lot of floor space. This can be off-set by using Spirals ahead of tables which have a relatively small footprint. It is however a practical limitation on the size of tin plants.

San Rafael Plant , Peru which is built on the side of a mountain in the Andes, created space using Spirals and reducing Table numbers when they increased throughput in the early 90s

San Rafael in Peruvian Andes
4600 metres

EQUIPMENT DEVELOPMENT

Of the Centrifugal devices developed, Kelsey Jigs, Knelson, Falcon, and Mozley MGS – the **Falcon Concentrator** has emerged as the most useful for fine gravity and flotation beneficiation.

Fine Screening has come a very long way – e.g. **Derrick Screens** USA can now screen down to **45 microns**, and such screens are being specified for Primary Grinding and Regrind circuits of existing plants and new projects.

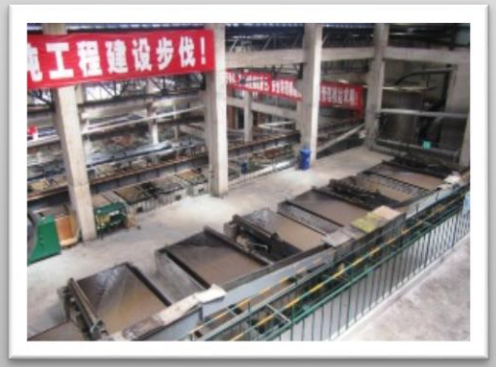
Flotation was introduced into Australia about 1970 – Before that **Slime tables** and **Vanners** were used for fine tin recovery.

Mini-cyclones developed for the Kaolin industry in Germany were adopted when it was realised that efficient feed de-sliming is an important part of the tin flotation process.

In **Chinese** plants **Shaking Tables** are the preferred beneficiation method - there are some plants still using Vanners. China does not use spirals or tin flotation as far as the writer is aware

There maybe still a case for using Vanners for some applications.

Shaking Tables and Vanners



GRAVITY PLANTS IN CHINA

PROCESS CONTROL

Steady feed at optimum tonnage rate is an operating objective for ore treatment plants.

Using Manual Operator Control the process is always kept below optimum by the operators to stay out of trouble with overflowing bins, pump boxes and the like

When automatic process control began to be adopted in the late 60`s , there was a huge control room with mimic diagrams, large instrument dials and stop-start push buttons in the panel – it seemed space age then - looks primitive now.

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EARLY PROCESS CONTROL COMPUTER

The Ubiquitous Fox 1

in a museum now

SIGNIFICANT CONTROL ADVANCES

The use of **Variable Speed Drives** was limited way back as they were expensive and occupied a lot of space, however there was a major change when Frequency Converters were introduced and Thyristor controlled motors could be **installed throughout the plan**t and hooked into the process control system.

This provided bin and pump box level control, vari-speed belt and vibratory feeders, pH control, better weightometers, automatic valves, pulp density and flow metres to give mass flow

Computer advances led to PLC Control and Screen Display in smaller control rooms. Now operators can all have iPads and maybe no control room will be installed in future plants.

In regard to assay of key plant streams the old method was to take shift samples and get assay by **wet chemical method** 24 hours later !! Not very useful but highlighted problems for remedial action, and was essential for the Metallurgical accounting

The Introduction of X-ray fluorescence (XRF) and Atomic Absorption (AA) improved that to 2 hours and later On-Stream Analysers (OSA) which gives assays every 5 minutes on a number of elements.

NOTE Renison Tin, Tasmania, was one of the Pioneers of OSA working in close collaboration with AMDEL from Adelaide about 1970

TIN FUMING

To achieve further improvements when all normal Mineral Dressing methods have been employed **Fuming** may be the best method for complex primary ores such as Consolidated Tin Queensland Mt Garnet (Gillian Ore) and tailings at a number of mines around the world as it can give a high grade tin concentrate at high recovery from low grade concentrates.

The challenge is to find a cheap furnace and associated gas handling system. The chemistry is simple – heat and melt the low grade concentrate, add carbon in some for to create a reducing atmosphere, add sulphur in some form – not much. The Tin oxide converts to Tin sulphide which rises out of the molten mass, add oxygen via blowing in air, the reaction reverses to Tin Oxide Fume and Sulphur-dioxide. The tin fume which looks like talcum powder is caught in Bag filters, the sulphur dioxide gas is wet scrubbed and neutralised with lime.

This process gives high grade tin and high recovery and can the be smelted by traditional methods.

ALLUVIAL DEPOSITS

Nearly half of the tin concentrates produced globally are from Alluvial Deposits

An alluvial deposit is assessed by Bangka Drilling or Pitting but accurate assaying for tin is difficult below 0.3 % Sn. Alluvial tin is far below this level

A method has been developed where a known volume of alluvial is processed to concentrate the contained cassiterite to a level where it can be assayed then expressed in weight per volume.

Typically some fraction of a cubic metre is reduced by screening out the coarse material at say +3mm, then gravity treating the -3mm fraction by panning or tabling to produce a tin concentrate which can be weighed and assayed, and related back to the initial volume. Somewhat simulates the commercial process.

ALLUVIAL ASSAY METHOD

In Indonesia and other parts of South East Asia, the final panning is done in a Dulang. The assay obtained is often referred to as "gravity recoverable" tin as at such low grades the use of fines recovery methods such as centrifugal and flotation is not practical and cannot be economic. Fine tin loss is academic as could not recover any way

Kg of Tin per Cubic Metre is the preferred unit adopted now.

Note that the assay is sometimes given as Cassiterite (SnO_2) not Tin (Sn) Cassiterite is 78.7% Sn

Alluvial Tin Concentrates produced for sale to Smelters typically assay 74% Sn the balance usually being silica, some residual heavy accessory minerals such as Ilmenite, Zircon Monazite and Rutile - the theoretical highest concentrate grade is 78.7% Sn.

High recoveries are reported as it is based on the assay determined initially by gravity pre-concentrating and takes no account of any fines lost – academic anyway as cannot recover

ALLUVIAL PROCESSING

Alluvial processing involves mining by Hydraulic Monitor, Mechanical truck and shovel, or dredging on-shore or offshore, screening to remove coarse gravels gravity pre-concentration in wooden sluices or jigs. The specific gravity is 7.0 and easily separates from the low S. G gangue and they a free particles

The rough concentrate is sent to a Central Dressing Plant and upgraded through, gravity, magnetic and electrostatic processes. The accessory Heavy Minerals are also recovered here.

I Kg of tin per cubic metre is regarded as bonanza grade and depending on mining methods, dredging, open pits, gravel pumping etc, depth of deposits, economies of scale and location/infrastructure, current cut -off grade is around 0.2 - 0.3 kg Sn per cu metre, and for new projects, + 0.3 or higher is sought.

A new high capacity dredge, say 600,000 m^3 per month, costs around US$50 - 60 million – not cheap any more.

There is more off-shore mining with small Cutter-Suction dredges Operating in Indonesia as land based resources are depleting.

SUMMING UP

Processing of tin ores has progressed considerably over the past 40 years and this trend will to continue as Operators persist with finding better solutions through **R& D** and **Continuous Improvement Programs** normal in any operating plant

Tin Fuming should be pursued as the next tool in the Metallurgists armoury

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Tin Process Equipment - Photos and Graphics below

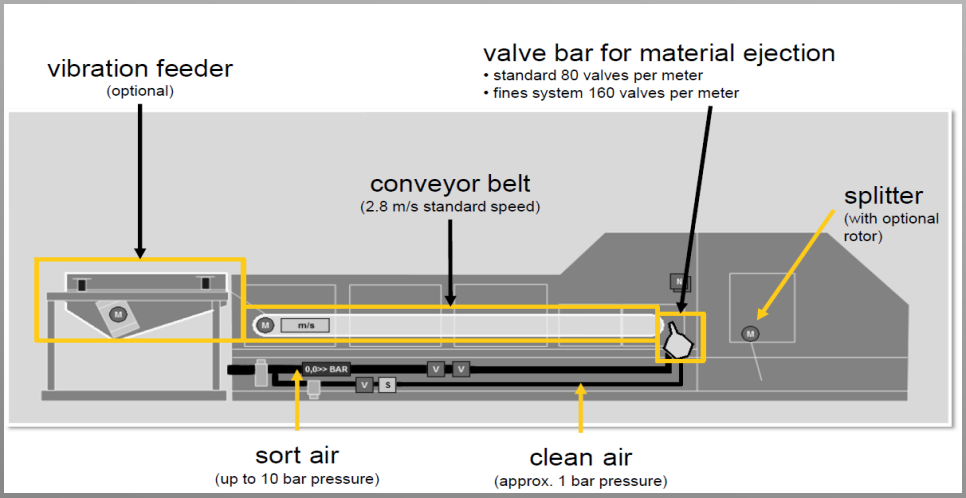
Bangka Drill and Alluvial Operations

SENSOR ORE SORTING

In developing a mineral process flowsheet the ore mineralogy is studied, and based on this an ore characterisation program is embarked on, which will include assessment of amenability to pre–concentration.

The practical mineral dressing options to achieve a separation using the properties of minerals are size, specific gravity, density, magnetic susceptibility, conductivity, colour, floatability and solubility.

Ore Sorting Sensors can be selected to make use of a number of these properties and applied to determine the pre-concentration potential e.g. Density by X-ray and Colour by Optical sensors.

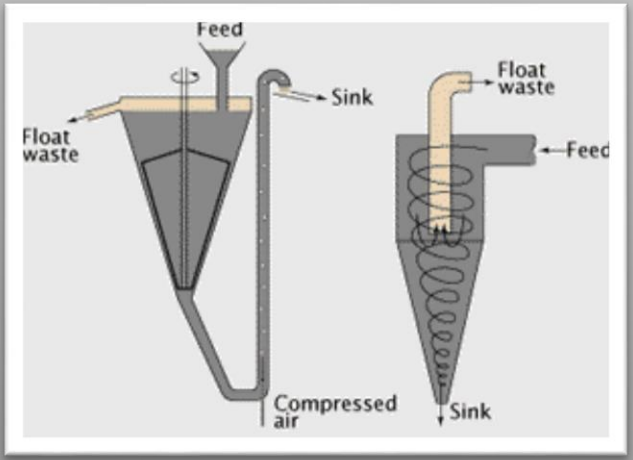


Click to play video
http://youtu.be/os7KFzRfaN0

SENSOR ORE SORTING

HEAVY MEDIA PROCESS

Crushed ore is passed through a bath or cyclone in a fine suspension of heavy mineral - usually magnetic ferrosilicon (Fe Si) for minerals. The Heavy Minerals in the ore penetrate the media and the light minerals float achieving a separation The Ferro-silicon is recovered by wet magnets and recycled.



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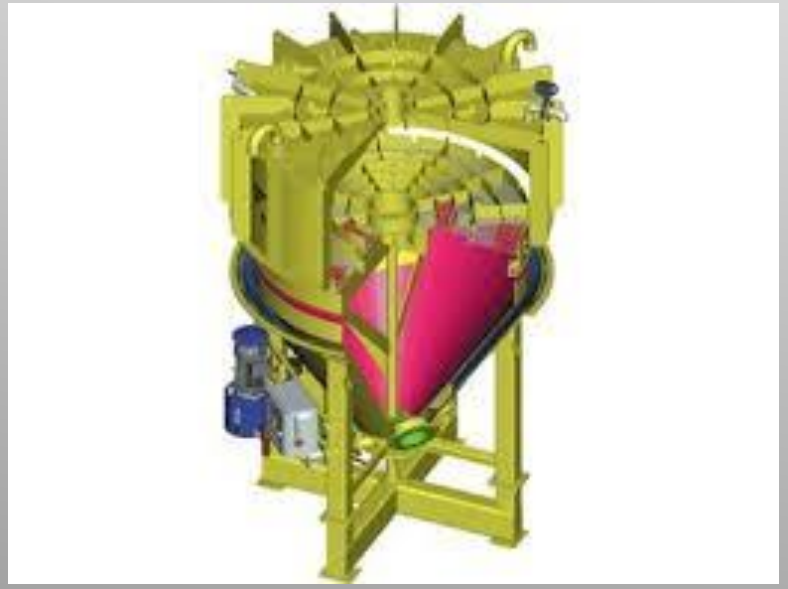

GEKKO JIGS

Fine Wet Screening for use in grinding circuits

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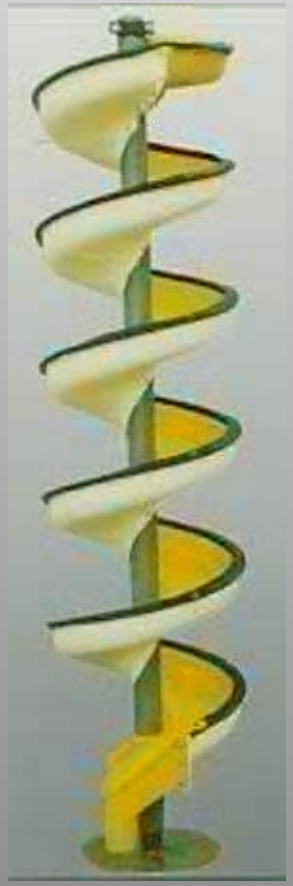
STACKED SCREENS WITH DISTRIBUTED FEED PULP

Can screen down to 45 microns Kevlar reinforced polyurethane screen material

FINE SCREENING

Spirals - General Ideas of Shape & Size

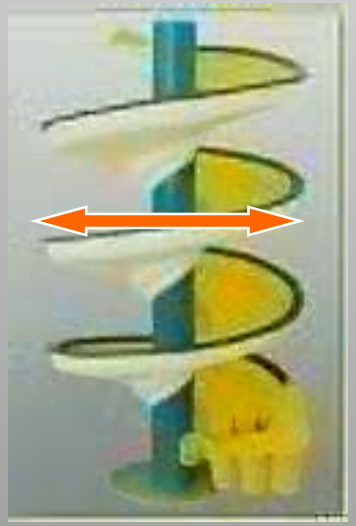
5 –Turn Mineral Spiral



640mm

Pitch

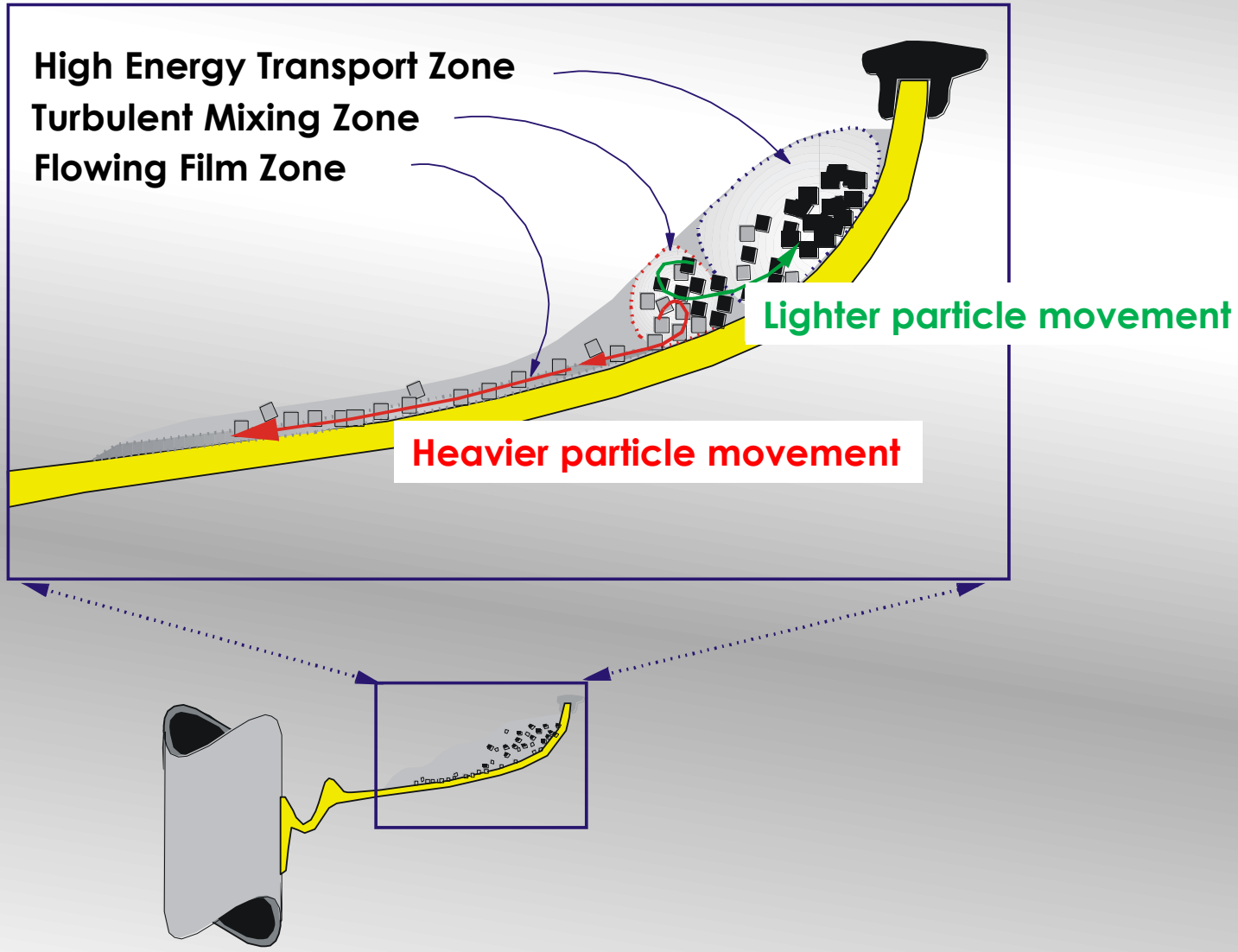
GP Coal Spiral



960mm

Profile - Pitch - Turns

Particle Movement and Separation on Spiral



Operating Spiral

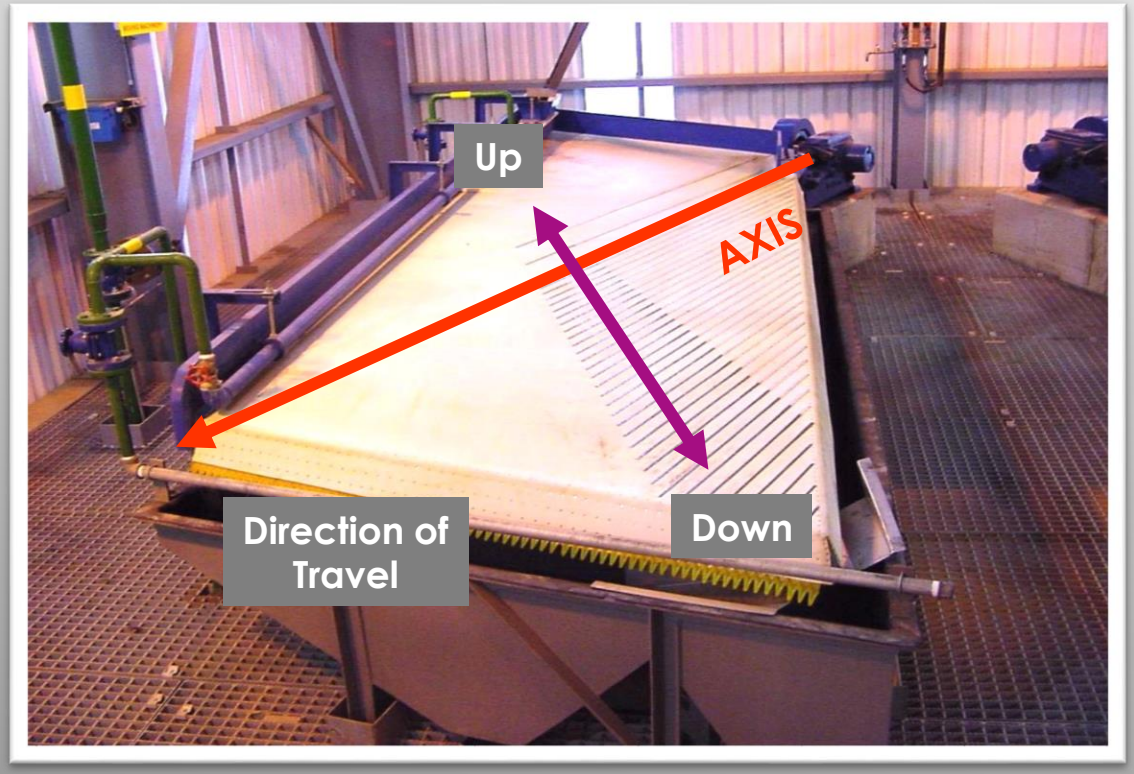
SPIRAL ADVANTAGES

Why Spirals Anyway?

- Low capital per tonne of material treated
- Simple installation of equipment
- Very low operating costs
- Little or no supervision required
- No moving parts
- Very low maintenance costs
- Tolerant of changing feed conditions
- Visual appreciation of separation
- No scale-up problems
- Environmentally friendly

Test Facility & Modules for Shipment

The Table Movement Promotes Efficient Separation by Mineral Specific Gravity



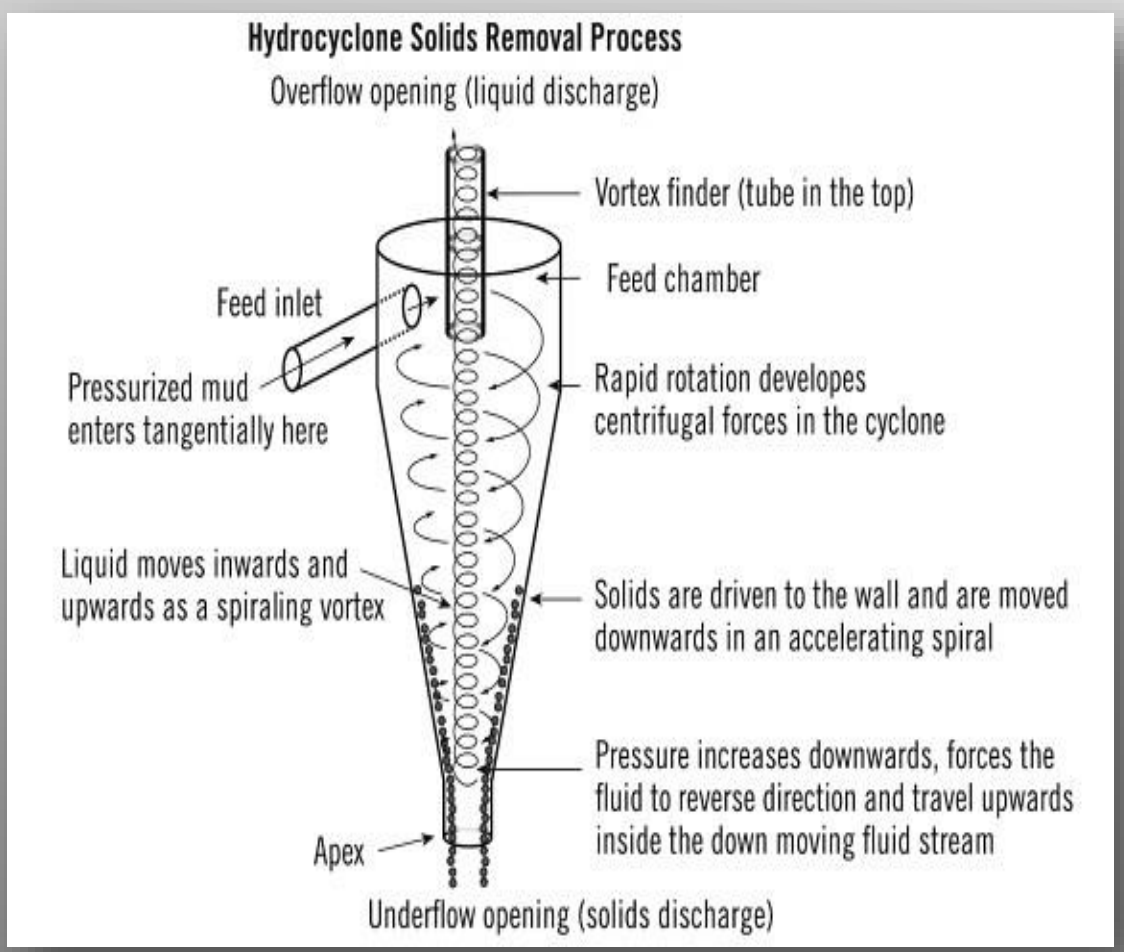
SHAKING TABLE

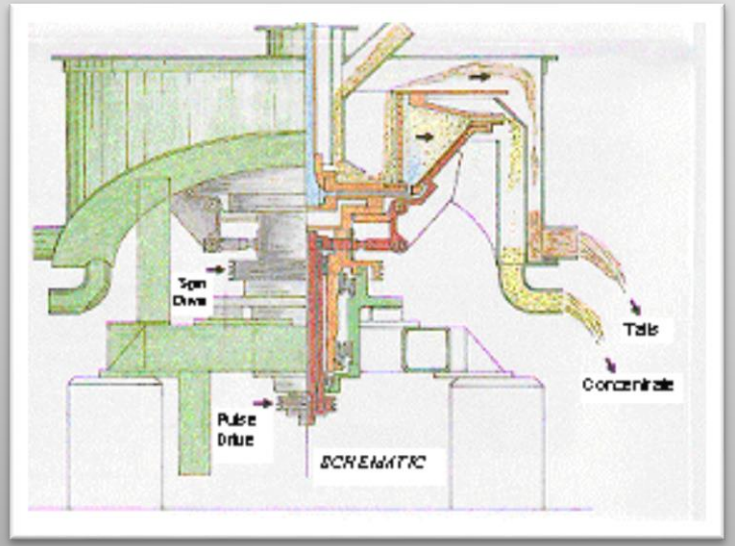
Treating Spiral concentrates

SHAKING TABLES
TYPICAL INSTALLATION

Mini-Cyclones for Desliming –

Adopted from the Kaolin Industry





KELSEY JIG

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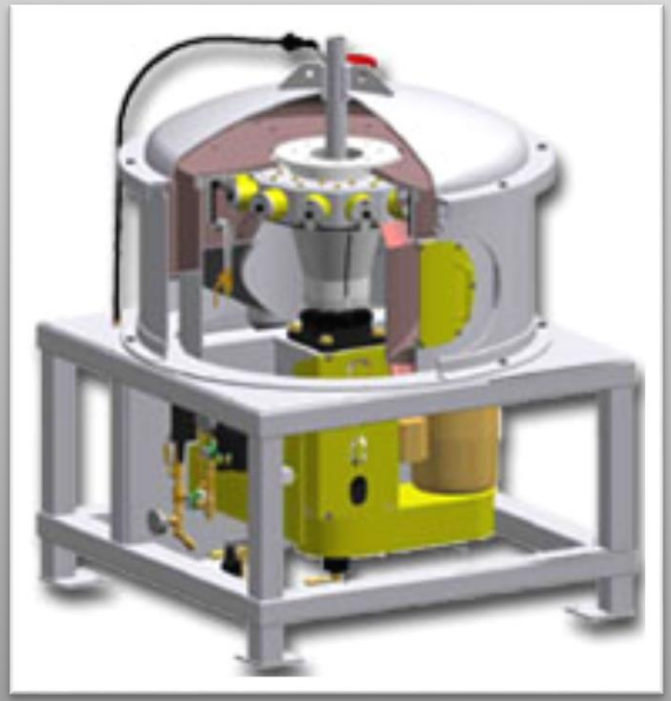
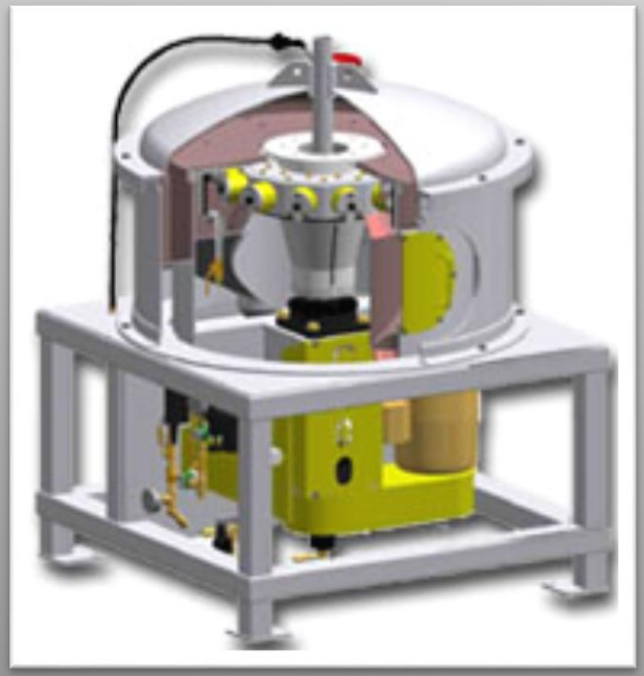
Continuous

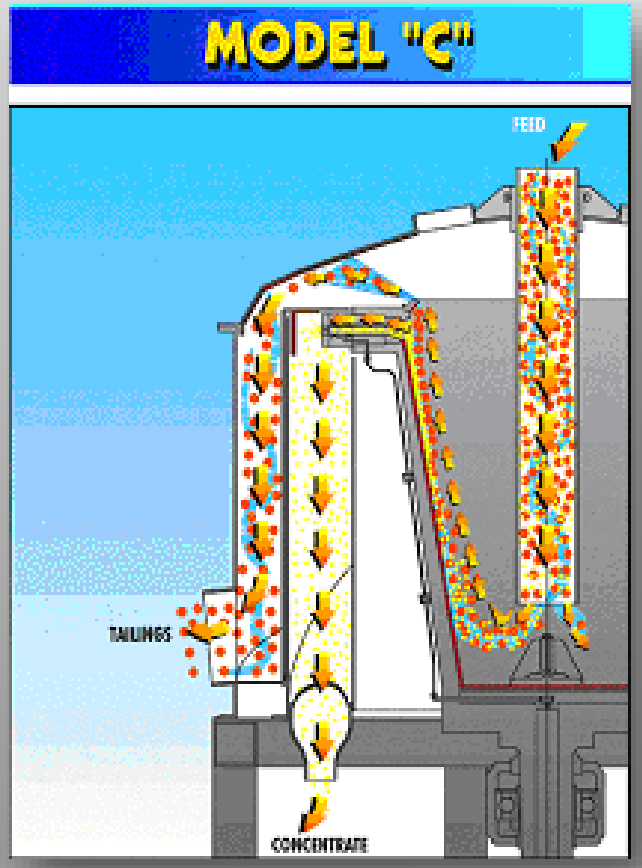


Batch

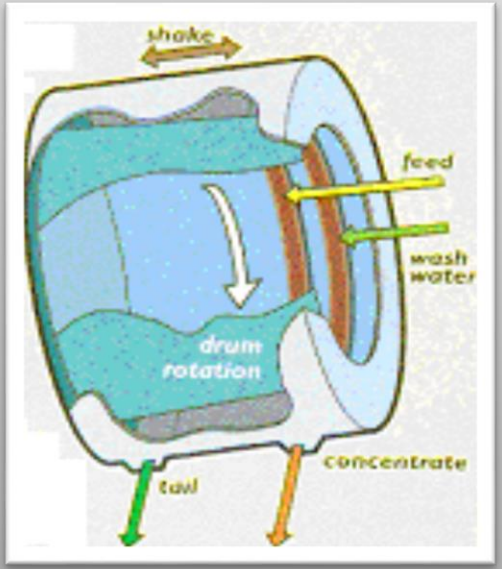
FALCON CONCENTRATORS

Falcon Concentrators Continuous





Mozley MGS



THANK YOU
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