MINERAL BENEFICIATION

Elements of High-Capacity Gravity Separation

I. J. Terrill and J. B. Villar,
Mineral Deposits Ltd.,
NL Industries, Inc.,
Golden, Colorado

Abstract

The role of gravity separation and current trends in circuit design are reviewed with reference to recent plants for alluvial, beach sand, hard-rock and tailings scavenging applications. Reference is made to integrated systems for treating long-size-range ores and the role of other separation techniques in conjunction with gravity circuits.

The bases of high-capacity gravity separation systems are discussed, with emphasis on the necessity for economic engineering design, materials handling, pumping technology and water control. Particular reference is made to the application of the Reichert Cone Concentrator outside its traditional mineral sands role.

The necessity for controlled liberation of values, adequate feed preparation and the selection of suitable surge devices between stages is emphasized, in conjunction with suitable instrumentation and rate control systems.

Introduction

THE LAST TWENTY YEARS have seen significant advances in gravity separation circuit technology which have resulted in the efficient operation of high-capacity plants on a variety of heavy mineral/gangue assemblies.

Ian Terrill is the chief metallurgist of Mineral Deposits Limited, Southport, Queensland, Australia. He is a graduate of the Royal Melbourne Institute of Technology and is currently acting as a consultant to the Mineral Resources Department of N L Industries, Inc. in Golden, Colorado.

Jess B. Villar completed his Bachelor's degree in mining engineering at Mapua Institute of Technology in Manila, Philippines in July, 1963. He worked successively as assistant mine engineer and chief mine engineer from 1963 to 1966 with Samar Mining Company in Davao, Mindanao, Philippines. During this period, Mr. Villar was the acting mine safety engineer for the company, and was selected by the Philippine AIME as the best surface mine safety engineer for 1965.

He attended the University of Minnesota from September 1966 to March 1968, undertaking major studies for his Master's degree in mineral engineering.

Mr. Villar worked successively as process metallurgist and senior plant metallurgist from 1966 to 1971 at the MacIntyre Development (New York) of N L Industries. In July, 1971, he was assigned as project metallurgist with the Mining and Exploration Department of N L Industries, where he was directly in charge of the technical marketing of the Reichert gravity equipment. Mr. Villar was promoted to group metallurgist in 1974 with the same department, and since January, 1975, he has been assigned as project engineer for N L Industries' proposed 3,000-mtph Reichert cone mineral sand plant in Maxville, Florida.

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The most consistent advances have been made in the treatment of particles in the 3-mm to 50-micron (6-270 mesh Tyler) range, where high-feed-density, high-capacity separators such as the Reichert Cone have been developed.[1]

Spiral separators have been refined and modified to permit greater capacity within a given space and it has been recognized that they should be designed and assembled to suit the particular mineral assembly treated, with particular attention paid to separating surfaces and wash-water addition.

Some research has been carried out on new forms of jigs capable of handling a wide particle size range and significant mechanical improvements have resulted. The ability of jigs to give high recoveries on very fine particles is limited and complementary systems are used where practical performance drops to unacceptable levels. The jig remains as the most efficient gravity separator in the coarser size ranges.

A significant improvement in the concentration of heavy minerals in the 50-10-micron range has been achieved by the development of the Bartles Moseley Concentrator, which has been successfully tested at high recovery on fine tin and tungsten ores at rates of around 5 tph per unit.

These developments, coupled with improved pumping technology and instrumentation, provide the modern metallurgist with the opportunity to design significantly more efficient and compact gravity circuits.

The rapid advances made in other separation fields, notably high-intensity magnetic separation and froth flotation of tin and tungsten minerals, have led to more flexible design systems in which lower-quality gravity concentrates can be selectively upgraded at high recovery by more expensive or difficult processes once the bulk of the gangue has been removed. This review paper summarizes the state of the art, using as examples recent plant designs and installations.

Role of Gravity Separation

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, heavy-media and similar systems. The trend to treat larger tonnages of lower-grade mixed mineral ores made the traditional systems involving jigs and shaking tables less attractive, except in the case of tin, tungsten, iron ore and similar assemblies. The development of the spiral concentrator opened up new applications due to its simplicity and cost effectiveness, but, in recent years, large multistage spiral plants have proven relatively expensive to install and to operate, as labour, power and capital charges have increased.

In Australia in the 1950's, the mineral sand industry was faced with declining grades and cost increases, which made spiral plants marginal to construct and operate. Various forms of pinched sluice separators were developed, including the Reichert Cone Concen-

-trator. This unit was originally conceived as a large-capacity preconcentrator, but with increasing circuit sizes it has been developed to operate effectively in a cleaner and recleaner role, producing concentrates grading in excess of 95% heavy minerals. Its further application outside the mineral sand industry is discussed below.

In recent years, the cost and availability of flotation reagents, leaching agents, ferrosilicon, fuel and power have led to a re-evaluation of gravity systems by some companies. Ecological pressures and metal prices (e.g. gold) have also contributed to this rethinking. Recent studies in South Africa have indicated that, at current prices, the extraction of a larger proportion of their gold by gravity and amalgamation can be justified by decreased soluble losses in the main cyanidation circuits. In many cases, a high proportion of the mineral in an orebody can be at least preconcentrated effectively by cheap, and ecologically acceptable, gravity systems. The amount of reagents and fuel used in processing a given ore can be cut significantly when the more expensive systems are restricted to concentrate flows. The gravity separation of mineral at coarser sizes as soon as it is liberated can also have significant advantages in later treatment stages, due to decreased surface area, ease of handling without dusting and the absence of adhering chemicals which could interfere with further processing.

Recovery of residual valuable heavy minerals from flotation plant tailings streams using spirals and cone concentrators has led to several large installations. The Climax molybdenum mine tungsten by-product plant and the Palabora heavy mineral recovery operations in South Africa are two good examples of how very fine low-grade tailings flows can be successfully treated by gravity systems. There are many similar applications throughout the world where low-cost gravity separation could be successful. Apart from current flows, there are many large tailings dumps which could be cheaply remined and processed into high-value streams using recently developed technology.

Gravity Separation Equipment

A rough classification of the more commonly used gravity separators can be made on the basis of feed size range.

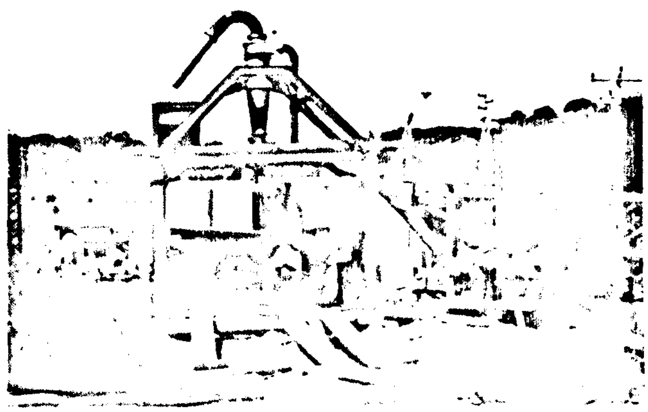
Jigs	25 mm to 75 micron
Pinched Sluices & Cones	3 mm to 30 micron
Spirals	3 mm to 75 micron
Shaking Tables	3 mm to 15 micron

A typical long-size-range alluvial cassiterite orebody could call for the use of all the equipment listed, depending on the mineral distribution and the upgrading required.

Effective, economic liberation and classification is commonly more important than the actual separation process, in that all gravity equipment is sensitive to the nature and manner of presentation of the feed material. Once liberated and classified, a gravity feed can be presented in series or parallel to the higher-capacity jigs and pinched sluice systems, with the lower-capacity spirals and table systems used for upgrading primary concentrates or handling smaller higher-value flows.

JIGS

Many large jig circuits are still operated in the cassiterite, tungsten, gold, barytes and iron ore industries. Most jig units currently available are based on designs established earlier in this century. A notable exception is the circular Cleveland jig marketed by I. H. C. Holland, which has been designed in several sizes, primarily for floating-dredge operation. This type of unit has distinct advantages in terms of single-point feed distribution and a radiating material flow which assists the controlled jigging process.



I. H. C. Jig recovering cassiterite in northwestern Brazil.

Jigs have a relatively high unit capacity on nominally classified feed, and a combination of screen and hutch products can achieve good recoveries of values down to 150 microns and often acceptable recoveries down to 75 microns. High proportions of fine sand and slime interfere with performance and the fines contents should be controlled to provide optimum bed conditions.

The finer fractions of jig tailings can often be economically scavenged on cone concentrators, sluices, spirals or tables, after elimination of the +3-mm oversize.

PINCHED SLUICE SYSTEMS

Pinched sluices of various forms have been used for heavy mineral separations for centuries. Major developments in the art have been achieved over the last 20 years, particularly in the mineral sand industry in Australia, where many high-capacity (100-1500 tph) plants have been established using various systems of pinched sluices.

The most widely used unit, the Reichert Cone Concentrator, was developed by Mineral Deposits Ltd. of Queensland, Australia for the economic separation of rutile, zircon and ilmenite from beach sand deposits. A number of large circuits operate cones for primary, secondary and tertiary upgrading, with spirals providing finished concentrate for cartage to the drymill areas. Many plants, however, use only three stages of cone units to produce finished concentrate grading up to 95% heavy mineral.

The relatively high capacity, (65-100 ltph, depending on the application), absence of moving parts and high-density feed (60-70% solids), coupled with low floor-space requirements and light-weight construction, have made this unit standard equipment in most of the recent Australian plants. There are several other forms of pinched sluice concentrators used in

Australia, all of the tray type mounted in banks. Lack of flexibility, expensive distribution and high recirculating loads make them less effective than the cone systems.

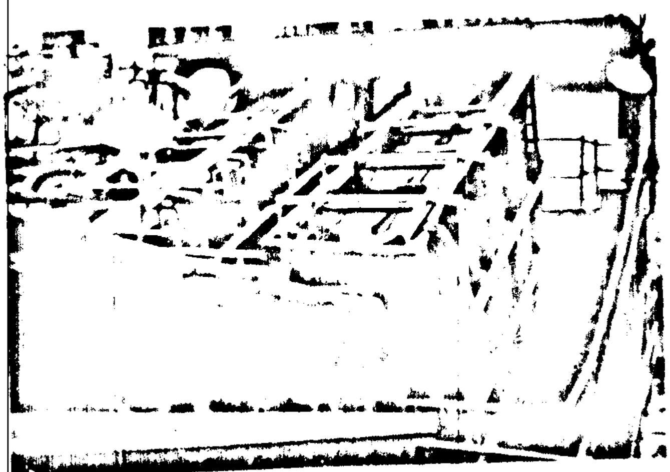
The success of cone circuits in the mineral sand industry has led to their application in other fields. Preconcentration of tin in grinding circuits, scavenging of urania and zirconia from the flotation tailings at the Palabora mine and the concentration of magnetite in New Zealand[7] are all recent successful applications. The units have been designed into iron ore fines beneficiation circuits for the Pilbara area in Western Australia, and a pilot operation is currently being commissioned in Quebec for the recovery of significant fine values from spiral plant tailings.

Acceptable recoveries down to the 30-micron range are being achieved in some applications and the strong classifying characteristics of the internal cone circuits can materially assist in preparing concentrates for upgrading on spirals and/or table systems.

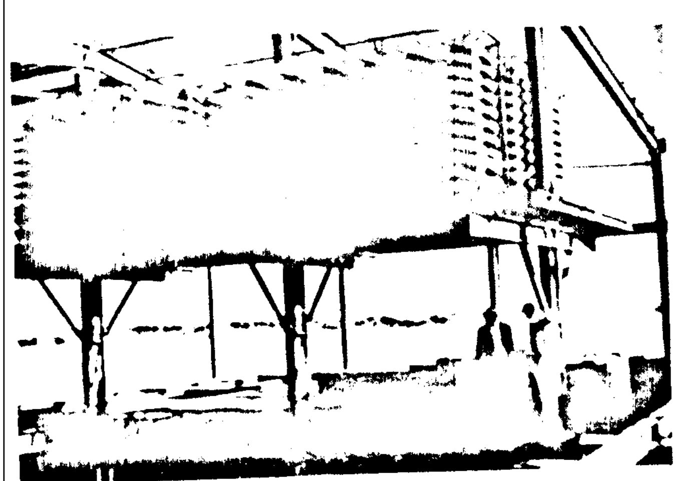
SPIRAL CONCENTRATORS

Spirals have been widely used in the sand and iron ore industries for several decades and in their modern form are still excellent concentrators, with very predictable metallurgy and great simplicity of operation.

Twin spirals, with two starts integrated into the one space around a common column, have been used in Australia for 20 years and have recently been accepted in the Canadian iron ore industry. Four-start spirals have also been used in Australia, but they do not have the same floor-area savings.



Dillingham trays in HM Sand Plant near Ballina, N.S.W., Australia.



Twin-feed Reichert spirals being installed near Geraldton, Western Australia.

The use of fibre glass and plastic as the basic construction materials with rubber lining has also improved the weight/capacity ratio to the point that a twin spiral capable of treating 2-3 ltph of feed weighs less than 150 lbs.

As many as fourteen twin spirals can be incorporated into a light pipe framework and installed as a module capable of treating up to 40 tph. The modules may be obtained complete, with integrated feed distribution systems, water galleries and product hoses. This approach lowers plant construction time significantly and provides for ease of maintenance and operation. Modular banks can be simply linked in rougher/scavenger and rougher/cleaner configurations with standard components. A typical rougher/scavenger assembly can be installed on two floors 12 feet apart, with only one set of launders to remove combined concentrates and scavenger tailing. Only light steelwork is necessary to support the modules.

Test work by Mineral Deposits Ltd. over many years indicates the desirablility of using two five-turn stages in series for many applications, with the rougher tailing re-mixed between spirals to give mineral lost to the "high water" in the primary spiral a chance of recovery in the scavenger unit.

The *wash water application* system is of vital importance to selective spiral separation. A recently developed system used on the Reichert MKII twin spirals taps wash water selectively from an enclosed channel by means of a rotating plastic quill. The quill supplies easily adjusted tubes, which can be directed against the pulp stream as required by the separation.

This blockage-free system overcomes many of the problems which have bugged spiral operators over the years since their initial development.

Splitter design is another area which has been the subject of many experiments by manufacturers and operators. Recent Australian experience on a wide variety of ores has indicated the necessity for several forms of spiral unit, with both pitch and splitter position altered to suit the application.

For example, the production of a high-quality concentrate containing little or no silica or lower SG minerals requires the use of a selective steeper-pitch spiral and a splitter system located in the trough in such a position as to accept only the better-quality particles. Fine difficult particles could be recovered more easily on a shallower-pitch spiral, with the splitter well out in the pulp stream.

Three basic forms of Reichert spiral are currently produced to conform to most application conditions. Splitters have been developed which can be located firmly into the rubber-lined fibre-glass troughs at varying distances from the central column. The plastic splitters are easily adjusted and removed if required, but cannot be knocked out of position and lost to tailings.

In general, the modern spiral concentrator still has wide application, provided the engineering and distribution systems are carefully designed to permit steady trash-free feed conditions. One operator can service up to 200 twin spirals if the feed and wash water are adequately controlled and screened. Poor engineering and feed preparation can result in significant increases in operating costs, down time and general maintenance. The very high pumping heads imposed by some current multi-stage spiral circuit designs do not assist economic operation. It appears that significant savings could be made by using cone units to handle the bulk of the upgrading at low head and high density, with spirals used for smaller residual streams.

SHAKING-TABLE SYSTEMS

Very few advances have been made in conventional shaking-table design, but the traditional units retain their flexibility and reputation as the most metallurgically efficient form of gravity separator.

Low unit capacity has always limited conventional table circuits to around 100 units. The introduction of triple-deck units has improved the area/capacity ratio at the expense of some flexibility and control. Except in the coal industry, capacities remain in the order of 0.75-1.5 ltph per deck, according to the nature of the feed and the separation required.

Conventional tables are most effectively used on the smaller more difficult flows and to produce finished concentrates from jig or sluice system products.

A *significant advance* in fine gravity separation hardware has been made in recent years with the introduction of the Bartles Moseley separator for the recovery of values down to the 10-15-micron range. This semi-batch system has proved effective, particularly on fine tin and tungsten materials, and at least one major installation is under construction. The relatively high throughput rate (4-6 tph) provides an economic system of handling reasonably large flows of fine ore with acceptable recovery and upgrading of values. These units achieve their good results from the necessary combination of large surface area and effective distribution.

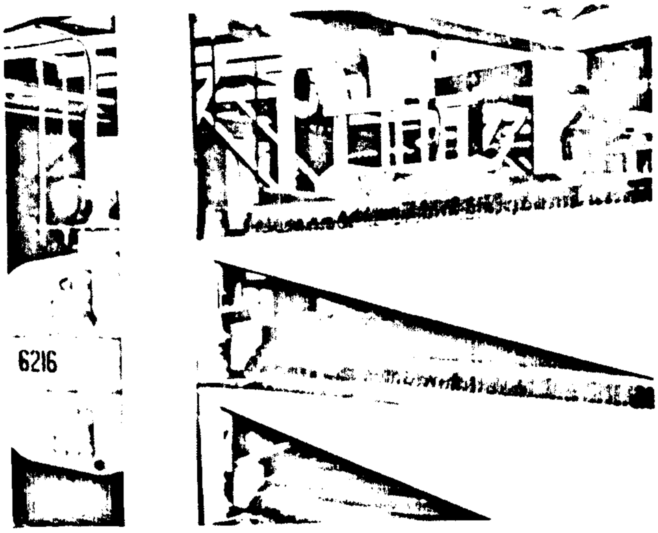
Effective fine screening is essential to prepare feed for the Bartles unit, but good results have been achieved in pilot operations using well-classified cone concentrate. It is apparent that cone concentrators, Bartles units and conventional slime tables can be effectively integrated to concentrate large low-grade flows containing fine valuable mineral.

Liberation and Classification

The importance of careful liberation and classification of gravity-circuit feeds cannot be overemphasized. The tendency of many valuable minerals, such as cassiterite and wolframite, to overgrind and be lost as fines renders it necessary to recover this type of mineral as soon as it is liberated. Gravity separation of the products of grinding and classification circuits at the earliest stage can lower the losses due to overgrinding.

Stage grinding using gravity separation on rod-mill discharge and subsequent ball-mill products frequently yields optimum recovery.

Unit jigs, cone concentrators and spirals can all be interposed into grinding circuits with some success. The jigs are particularly applicable where significant values can liberate at a relatively coarse grain size. Some problems can arise from the injection of too much hutch water into a grinding circuit and provision has to be made for accommodating low-density slurry as required. The cone unit has some advantages in that it operates at high density and can be fed with cyclone underflow without adding significant



View of part of the battery of nine Concenco "666" triple-deck shaking tables at Tantalum Corporation of Canada Ltd.

water to the circuit. The cone also recovers mineral particles down to 30 microns and its concentrates are usually smoothly classified and need little preparation for upgrading on spirals or tables. If sufficient tonnage is available, the naturally dense concentrate can be re-upgraded on secondary and tertiary cone units until the flow is small enough to justify the use of shaking tables.

Alluvial ores often require severe scrubbing, log-washing, screening and desliming in order to isolate the valuable components into flows which can be efficiently treated by the appropriate separation system. The exploration phase in alluvial mining operations should provide detailed physical analyses of the gangue in addition to mineral distributions.

The design of gravity feed preparation circuits for alluvial ground should be very conservative, because of possible severe fluctuations in the nature of the feed. Any deficiencies in the liberation and sorting processes tend to have drastic effects on the gravity separation stages. Metallurgical efficiency can easily drop 20-40% as a result of inadequate feed preparation. Materials handling, pumping control, housekeeping and plant availability are all very sensitive to the degree to which the ore is prepared for gravity processing.

There have been many cases in recent years where feed preparation requirements have been underestimated to such a degree that operations have either lost money or failed completely. The operating margin in alluvial operations is not usually very great and a large throughput of ore is often necessary to ensure a reasonable return. Efficient feed preparation permits optimum presentation of material to gravity systems and maximizes recovery and upgrading under conditions where an extra 5% of recovery can represent a 50% increase in operating profit.

Scavenging plants operating on tailings flows from existing circuits have their own particular feed preparation problems. The valuable minerals are often very fine through selective overgrinding in cyclone/mill systems prior to flotation or because they are rejected in the "high water" of inadequate spiral installations. Either way, the usual first step is to eliminate the slime particles which cannot be economically concentrated and any tramp oversize which may have entered the system.

If cones or spirals are to be used for scavenging, precise desliming and classification is esential to optimum metallurgy. Effective density control and a steady feed rate should be primary aims. Cones can be conveniently fed with cyclone underflow at 60-70% solids, but spirals have to accept thickened pulp or underflow re-diluted from the mill water supply. A combination of these units can often prove to be the most effective system, with appropriate shaking tables producing finished concentrate on the more difficult fractions.

Gravity Plant Design

Too frequently, large mineral processing plants are "designed" on the basis of similar operations which may have been conceived 30 years previously. This tendency to produce the old drawings and revise the structural details to accommodate larger equipment without reviewing the process concepts leads to stagnation in the technology.

Another serious tendency is for the process and mechanical design people to operate in separate compartments, whereby the flowsheet is turned over to the engineering groups and a minimum of interdiscipline consultation ensues.

The smoothest commissioned plants are those where experienced operators and maintenance people are closely consulted at each phase of the metallurgical and engineering design. New materials handling, liberation and separation techniques should be piloted at production scale where possible. It is often not recognized that a 100-200 tph pilot operation is ten to twenty times more effective than a 10-tph system, where the scale-up factor in liberation and/or materials handling conditions can lead to very expensive over- or underdesign.

Very frequently, a large pilot operation can be justified in that it forms a logical module for the final operation, which can be simply transferred, extended or incorporated into the main plant. Staff trained on a large pilot operation transfer smoothly into the extended operation and the data gathered form a good basis for production technology. On high-value streams, a good pilot operation can often retrieve a significant proportion of its costs in terms of stockpiled concentrate.

In summary, the proper design of high-capacity gravity plants requires an open mind, good orebody data, thorough pilot operations and cooperation between disciplines. The above statement may appear self-evident, but considering some of the operations built in the last decade it can bear repeating.

Metallurgical Design

In large gravity circuits, metallurgical design has to be very closely integrated with the materials handling and pumping processes, in that feed presentation conditions are frequently the major factor in obtaining efficient separation. The process design should not be too closely aligned to average ore conditions, but it should have adequate mechanical and metallurgical flexibility to permit efficient operation over the full range of ore conditions possible. This may mean an extra scavenging or cleaning stage in the process or perhaps extra desliming capacity to compensate for seasonal mining conditions.

In many cases, the question marks in the orebody can be covered at low cost by simply providing space for extra hardware, which can be rapidly installed as required. The almost inevitable demands for higher throughput are better handled by extra hardware than by overloading existing systems.

Where mining capacity is available, there is a strong tendency to try and produce more product by simply pouring more tons on the front end of a circuit without reference to the process variables. Unbiased metallurgical analysis usually indicates that a high proportion of the overload values report to tailings streams, sometimes only half liberated. Thoughtful specification of the unit process and transfer hardware can permit capacity increases or flowsheet extensions without interruption of production. Variable electric drives, pumps capable of operating over a wide range of capacities and distribution systems with extra outlets built in are all items which can be specified into the original flowsheet by the use of tonnage ranges rather than specific average values.

Very few plants ever operate precisely on the metallurgical balance so nicely derived on flowsheets and it is more realistic to express flows in ranges of tonnage and density conditions. The limiting particle size analyses of each flow are frequently more relevant to engineering design than flow magnitudes. The design of pulp and water distribution systems, launders and sumps is critical in gravity plants. Materials handling, flow density and dilution control are areas where the operators, metallurgists, and maintenance and design engineers can pool their collective experience to arrive at an optimum system.

SURGE FACILITIES

Adequate surge facilities must be provided in any gravity operation, as steady feed is usually a very important metallurgical separation factor. Ore storage bins, large sand collection sumps, agitation tanks, thickeners and large spiral classifiers all provide useful surge capacity in gravity circuits.

Apart from steadying unit process feeds, the inclusion of suitable surge points can often permit minor repairs to be carried out without completely closing down a circuit. Surge capacity and dewatering or classification functions can frequently be combined by the correct equipment choice.

ANCILLARY UPGRADING PROCESSES

Processes such as wet magnetic separation, heavy-media separation, flotation, leaching and precise classification are often integrated into gravity circuits as complementary systems which extract or treat particular mineral flows or selectively produce finished concentrates.

Mixed heavy mineral assemblies often upgrade more selectively by gravity after separation into magnetic and non-magnetic fractions. Elimination of magnetite, ilmenite and similar minerals by a combination of low- and high-intensity wet magnetic separation can frequently produce a non-magnetic fraction much more amenable to gravity treatment.

A recent instance where this has proven of great value was the treatment of an African heavy mineral sand concentrate containing a high proportion of "pyroboles" and unwanted ferromagnesian minerals. Extraction of a large proportion of the magnetic minerals as a crude wet concentrate permitted selective elimination of a high proportion of the lower-S.G. pyroboles and residual silica as spiral tailings, without appreciable losses of the finer, heavier rutile and zircon values.

Magnetic separation can be made more economical and selective through the use of prior gravity processes. Preconcentration on gravity units produces better-classified and more consistent magnetic feed. Similarly, magnetic separation can often be applied to gravity tailings to scavenge difficult particles after the bulk of the weight and values have been scalped out at grade by the cheaper process.

A recent example of *an efficient combination of low-intensity magnetic and gravity processing* is the Taharoa plant of New Zealand Steel Mining Ltd.[4] In that plant, up to 750 tph of variable-grade magnetic sand is preconcentrated at high recovery on a single stage of Reichert Cone units. A very consistent gravity concentrate containing the minimum of diluent middling particles is fed to two stages of complementary wet magnetic drum separators, which produce a high-quality finished titanomagnetite concentrate. Magnetic tailings are scavenged by gravity systems.

Direct magnetic separation of raw sand would have required double the unit capacity, and could not reliably produce the finished concentrate grade.

Wet high-intensity magnetic separation (W.H.I.M.S.) has been developed on a large scale in the last decade and a variety of units are now available for high-capacity applications.

The production of super-quality concentrates at high recovery from lower-grade gravity products is a potential large application. Gravity processing may substitute for the classification equipment usually necessary prior to wet high-intensity treatment, lower the over-all investment by reducing bulk and improve metallurgy by smoothing out the feed-size distribution curve.

Heavy media systems can be very successfully integrated into gravity circuits, due to the similarity in hardware and process parameters. The two systems are often compatible in that their products can be blended to produce a good combination of weight recovery and grade at reasonable cost. Heavy media separation of 2-6-mm fines coupled with a cone concentrator and W.H.I.M.S. treatment of minus-2-mm residues appears to form an efficient system for upgrading Western Australian iron ore fines. Similar combinations of cone units, spirals and dense-media cyclones can be used for efficient fine diamond recovery.

CLASSIFICATION

Precise fine classification techniques now available permit far better control of gravity circuit feed than was available two decades ago. Hydrocyclone technology alone coupled with improved pumping systems allows compact classification at each pulp transfer stage and can simply provide the high-density feed necessary for cone concentrator circuits.

Fine trommel screening, rubber screen cloths, sieve bends and other high-capacity improvements in classification technology all contribute to better control and economics of gravity circuits.

Spiral classifiers are very powerful tools in the gravity circuit designer's selection. They can provide significant surge capacity to absorb feed rate fluctuations and reliable non-critical classification down to

Reichert Cone Circuit, New Zealand Steel Ltd., Taharoa, New Zealand.

reasonable size limits. They can also dewater sand products for stockpile or further processing at controlled density. Coupled with hydrocyclones operating on either their overflows or providing a semi-classified feed, a spiral classifier offers a reliable transfer and sizing control system with relatively low power consumption and predictable mechanical performance.

SUMMARY

With the proven systems of separation, sizing and materials handling available to the modern metallurgist, it should be possible to design basic gravity circuits which can be rapidly constructed, smoothly commissioned and reliably operated at a high degree of metallurgical efficiency. Flexibility of mind and a reasonably conservative approach in specifying equipment capacities can result in new forms of circuits which can contribute significantly to general mineral beneficiation technology.

Mechanical Design

The mechanical design of high-capacity gravity circuits has made mixed progress around the world since the 1930's.

Design concepts are controlled to a large degree by mining and feed preparation requirements. High-weight-recovery or high-value ores are generally transported to a fixed plant located permanently at a central site, with tailings disposed of locally or by back loading. Lower-grade, lower-value ores often require that transport costs be cut by keeping the process plant adjacent to the mining operations, with immediate tailings disposal into mined-out areas.

The two forms of plant present quite different design problems and any one of other major factors such as topography, climate, availability of power, water and skilled labour can alter the complete philosophy.

FIXED PLANT CONCEPT

These systems are either fed intermittently by truck, train or conveyor, or continuously by pipeline from a dredge, mobile sump or a distant feed preparation facility. In either case, *adequate surge capacity* in the form of holding bins, sumps or stockpiles is necessary to ensure smooth feed conditions to the circuit and reasonable continuity of the process operation, regardless of fluctuations in mining rate.

The normal processes of crushing and comminution can be reliably controlled, but the proportions of each size fraction produced by routine scrubbing, screening and desliming of an alluvial feed is unpredictable. Under these circumstances, further surge capacity for each classification product is usually necessary. *For coarse products*, this can be provided by classifiers, and storage bins with feeding mechanisms.

Deslimed sand fractions can be adequately stored in large sumps and withdrawn by flooded suction pumping systems as required. These sumps frequently have working capacities of 600 to 1000 tons. They will supply high-density pulp to a 500-tph cone circuit for up to half an hour without replenishment, and effectively smooth out the effects of an intermittent mining feed for an indefinite period. Should the solids supply from the mining plant be interrupted or lowered to the point that the required density cannot be maintained, the main plant can be switched to water by opening a cone valve on the pump suction until sufficient solids have accumulated in the surge bin to resume concentration under controlled conditions.

Should the supply of sand-sized material from feed preparation consistently exceed optimum circuit loading, provision can be made to dewater the excess feed by classifier and stockpile it for reclaim when the mining units are having problems.

Very fine ore which will not settle adequately in surge bins must be held in thickeners or agitators prior to separation.

Distribution of coarse particles, sand and slime fractions to jigs, cones, spirals or tables must be accomplished steadily under controlled conditions. Jigs can tolerate some degree of irregular feed, but they operate best if fed at higher densities, with the hutch water regulated to control tailings dilution and separation conditions.

Jig feed can be gravitated, pumped or conveyed according to its size range. A typical system in alluvial operations uses the underflow of a single hydrocyclone as the feed supply for each jig.

Sand and slime fractions can be accurately distributed to cones or spirals or tables by a combination of pressure and gravity systems.

There are more sand distributor designs available than plant operators, but Australian experience is that the simplest systems with no moving parts have proven to be the most cost-effective in mineral sand operations.

Pumping system design is probably the most crucial area in modern gravity plants. With proper design and module selection under reasonable slurry conditions, duplicate pumps should be unnecessary, except in the most severe wear environments. Excessive pump wear is often a case of poor specification of pump duty or the imposition of unnecessarily hard conditions on a single pump in order to obtain an extra stage of separation by gravity flow. There are many older mills and some new ones where all the feed is pumped at excessive heads from grinding floors at the base of a hill to the preparation systems, which gravitate all products back down the circuit.

A one-level design with more, but understressed, pumps will frequently give higher availability and economy, as pump life is longer and more predictable.

Another strange feature of some modern plant designs is the number of short-radius, right-angle bends which are encountered in delivery pipework. With good delivery hose available, there is no reason why pumping systems should not flow in smooth curves to assist pulp flow and lessen the blockages.

Sump design is another neglected feature in many gravity operations, and several of the sumps appear to be derived from float plants and pump manufacturers' pamphlets. Each sump and pump suction system should be tailored to the application in terms of flow, size analysis, density and rate variations.

Sump level controls, stilling boxes, variable pump drives where applicable, simple-release suction hoses and indirect suctions with flood-off valves are all routine sand plant features which rarely appear in conventional gravity plants, where a single plugged sump can often close down a large circuit. The traditional "Florida Jet" sump design, which has been adopted and modified in the Australian mineral sand industry over the years, has a lot to recommend it in general gravity process plants. The ability to put a four-stage circuit on water by simply turning the flood-off levers on the operating floor and returning the circuit to density by the reverse action is a very valuable option in sand plant operation. The ability of selected sumps to mutually overflow and maintain levels without mill water addition is another feature of sand plant design which could be used to some degree in many other gravity systems.

Instrumentation plays a vital role in maintaining high average process rates under optimum conditions. Rate and density control can be maintained very reliably if sufficient feed is available for each process stage. A good example of instrumental control is the New Zealand Steel magnetite plant[2], mentioned earlier, where the primary plant feed is continuously analyzed and controlled using a combination of magnetic flow meters and gamma gauges. The system effectively maintains a consistent load of magnetic values in circuit regardless of large variations in the feed grade. The cone unit slots are also automatically varied with grade.

MOBILE PLANT CONCEPT

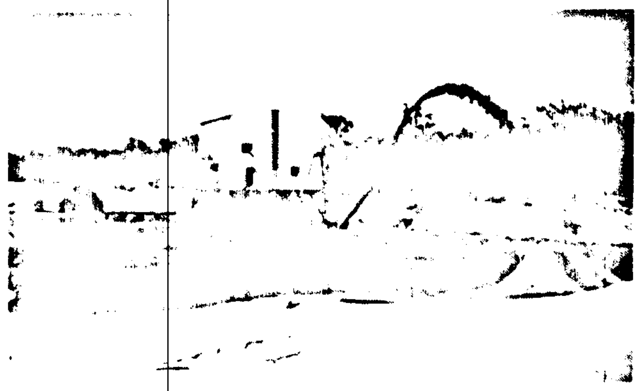
Extensive shallow alluvial deposits and scattered deposits of richer rock ores require mobile or semi-mobile plants which can move with the mining face and reduce the transport costs of ore and tailings streams. This mobility can be achieved by floating the process plant in its own working pond, or mounting it on skids, rails or tracks.

The large combination bucket dredge and jig plant units used for gold and cassiterite recovery are well known. Their basic design has not altered in many years, except for the addition of some pumping and cyclone desliming capacity.

The suction cutter dredge and separate floating plant concept which was pioneered in Florida has been developed into a very efficient system on the east and west coasts of Australia.

Total treatment costs for a ton of sand mined, processed, restacked and rehabilitated should not exceed $0.15 if a profit is to be made from current Australian deposits. This cost structure can only be achieved by a combination of economical high-density pumping to cone concentrators, a very low labour requirement and an integrated plant design which permits very high availability.

Where the orebodies have not been suitable for dredge mining, the floating plant technique has some-



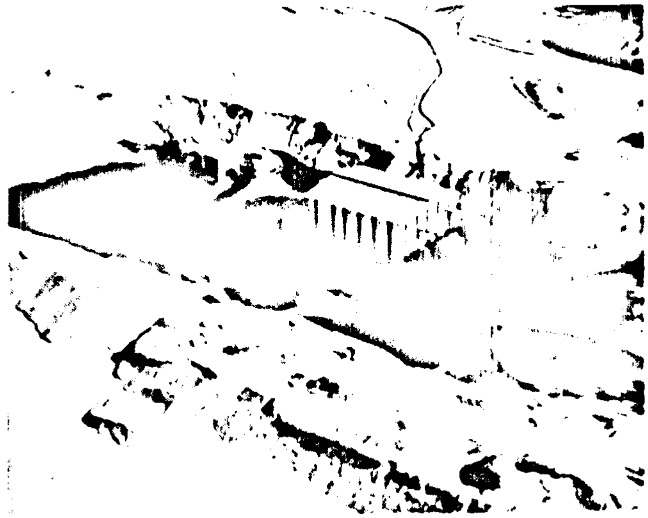
The Mineral Deposits Limited 280-tph Reichert Cone Gravity Plant in Eastern Australia. With the suction drèdge in the background, three men (per shift) run the system.

times been retained and the more expensive mechanical mining equipment such as bucket-wheel excavators, bulldozers and front-end loaders are employed.

Where floating plants are not viable, skid- or trailer-mounted modules have been developed that are capable of connection into gravity systems of up to 1000-ltph feed capacity. Some of these units move only every 6 months, others are relocated every few weeks and smaller units of 100-300-ltph capacity may move twice a week in some ore zones.

The majority of these plants use pinched sluice or cone concentrator systems for upgrading heavy mineral, but a recent rail-mounted cassiterite recovery plant in Rondonia, Brazil, has been designed to treat long-size-range feed through jigs and spirals at over 200 tph.

A recently commissioned 650-ltph plant in Western Australia consists of five track-mounted modules. Module 1 is a scrubbing, coarse screening and transfer unit. Module 2 carries hydrocyclones, a secondary trommel screen and a surge bin. Modules 3 and 4 contain a series cone concentrator circuit which produces 80-90% H.M. concentrate from 5-10% H.M. feed. Module 5 attritions and upgrades the primary gravity product using a three-stage spiral circuit.



The 600-tph floating Reichert Cone Plant of Mineral Deposits Ltd. in Eastern Australia.

A heavy mineral concentrate containing very little low-value mineral is produced for transport to a dry mill over 100 miles away. Individual modules can be towed by a single bulldozer.

As in the field of metallurgical design, the technological advances made in the last 20 years result in new concepts in engineering systems, thus allowing the economic working of orebodies once considered to be marginal.

For those prepared to trust their technical judgment and ensure the reliability of their design datà, many interesting and profitable gravity-based operations lie ahead.

References

(1) Graves, R. A., The Reichert Cone Concentrator — An Australian Innovation. Mining Congress Journal, Vol. 59, No. 6, pp. 24-28, June 1973.

(2) Buist, D. R., Cooper, R. H., and Terrill, I. J., Recovery of Magnetite at New Zealand Steel Mining Operations, Taharoa, New Zealand. Fall Meeting, SME of AIME, September 1973.

Exploration Geochemists to Meet in New Brunswick

A REGIONAL MEETING of the Association of Exploration Geochemists will be held at Fredericton, New Brunswick, in 1976, scheduled for April 22-25. "Exploration Geochemistry in the Appalachians" will be the subject of the meeting. Field excursions are being arranged for April 24 and 25.

Details are available from Prof. G. J. Govett, Department of Geology, University of New Brunswick, Fredericton, N.B. The deadline for synopses of papers is November 10, 1975.

Chemical Conference Features Session on Science Policy

A MAJOR SESSION on science policy will be featured at the 58th Canadian Chemical Conference and Exhibition of The Chemical Institute of Canada (CIC), Toronto, Ontario, May 26-28, 1975.

This session, "At the Interfaces — Scientists, Government and Society", will have three speakers. Dr. Maurice LeClair, secretary, Ministry of State for Science and Technology, Ottawa, will speak on relations between government and the scientific community. James Mullin, deputy executive director, Science Council of Canada, Ottawa, will speak on science, science policy and national problems. Dr. Dennis Tuck, chairman, council of Canadian Universities Chemistry Chairmen, will discuss problems of university research funding in the 1970s.

For details, contact CIC, 151 Slater St., Ottawa, Canada K1P 5H3.