GRAVITY CONCENTRATOR DESIGN AND OPERATION—DEVELOPMENTS AND PROBLEMS

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e treatment of tin ores is still performed mostly by gravity concentration. The rrent high price of tin demands that greater efforts yet be applied urgently to prove the metallurgical and economic performance of tin concentrator erations. Recent developments in gravity concentration technology clearly ow that significant improvements can be achieved to existing plants, even for e recovery of fine tin values, provided that the losses are not in a refractory rm in the ore itself. The design of new gravity plants using modern equipment, aterials, good engineering and fabrication techniques can be substantially ore efficient than in existing plants, and they can be built with significant onomies in capital and in operating costs. The treatment of lower grade ores d the fuller utilisation of natural resources may thus be possible and profits nerate d even at tin prices below the present high levels.

The major factors which influence existing plant performance and cause poor etallurgical results include ore variability; drilling and blasting practices in the ne; weaknesses in design, in the flowsheet and in equipment selection; ergrinding in primary, secondary and regrind mills and insufficient process ntrol, resulting in poor operations. Means for improving the recovery of tin d other economic benefits in existing plants and for new plants are discussed. ecific features of new plant design, including recent new separation processes d other equipment are briefly described. The role of on-stream analysis is o mentioned.

t should be stressed that although of general interest, this article emphasises pects of gravity concentration that relate to the Bolivian tin industry.

HERE have been significant develop-nts in recent years in gravity separa-n technology, which is still the ajor process used for tin ore treat-nt. The development of a number new machines for the actual separa-n of the valuable minerals, and in ner processing equipment has been bstantial also in engineering design d the interpretation of metallurgical ocess requirements into a quantitative wsheet; in materials used for the anufacture of equipment; in the plication of automatic control systems d of on-stream sensors, coupled with gital mini-computers and in the erall understanding of factors impor-nt to the operation and economics of e processing plants.

ew concepts

Many of these advances have been nployed in the design of large con-ntrators of up to 1500 ton/h capacity r the treatment of beach sands[1] d in large plants for processing of n ores and of raw coal. To a very nited extent these new concepts have been introduced into smaller gravity concentrators including a number of plants treating tin ores. There is considerable scope for further implementation of these developments into tin concentrators, and this paper will attempt to review and comment on a number of these topics, with the objective of providing an awareness of their technical and economical potential. Some concepts as yet untried or fully proven are also discussed and these may provide further stimulus for the design, construction and operation of new plants and toward the improvements of existing gravity concentrators and their operation in Bolivia. It is suggested that improvements in actual tin recovery of 5 to 10% may be achieved and, in some instances, by only modest capital investment. Clearly the improvements in revenues and cash flows that might be accomplished from higher recovery, better concentrate grade, more throughput or lower operating costs, can only be established from a careful and thorough study, beginning with a diagnostic analysis of the plant operations, equipment and personnel. The current high price of tin, in excess of $5.00/lb at the time of writing, could justify even substantial capital investments, if necessary, to achieve an increase in tin recovery of 5% or less. The beneficial effects of plant improvements on other aspects such as ore reserves, cut-off grade, mine life and the more efficient utilisation of natural resources, would also be significant. Profitable operation of well designed and operated plants using available technology should also be possible at much lower tin prices.

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Present tin concentrator performance in Bolivia

In 1964, the metallurgical data reported for 12 COMIBOL plants were summarized as follows[27]:

	Feed Grade % Sn	Combined Conc. Grade % Sn	Recovery % Sn
Average	0.81	34.08	49.1
Range	0.54–1.84	19.97–57.5	27.3–65.7

Since 1964, significant improvements have been made in most of those plants and many have been expanded substantially and modified in various ways. Over the past 13 years, ore grades have declined, probably, in every operation. In 1964 the average ore grade of the Llallagua mine, for example, was reportedly 0.54% tin and at present is apparently about 0.35%. Lower ore grades and the increasing complexity and refractory character of many of the ores have put considerable pressures upon the urgency for improvements in metallurgy from those prevailing in 1964 and on the overall economics of most operations. Profits have been eroded by substantial increases in operating costs over this period for labour, operating and maintenance supplies, power and other services. Without the higher price of tin, many of the operations of COMIBOL, as well as mines in the private sector, would perhaps now be in serious financial difficulties or shut down. A significant number of properties have, however, continued to be profitable only by mining of larger tonnages and of lower grade ores.

It is recognised that many of the Bolivian tin ores are complex and difficult to process efficiently and that in some instances improvements in tin recovery and in maintaining or increasing profits may be difficult to achieve. It is understood that the technical and management personnel in the tin industry are already actively engaged in and are doing many things to improve the profitability of their operations and to enjoy more fully the economic benefits of the current high price of tin. Hopefully, some of the information given here will be of further assistance in this regard.

Losses in Sn concentrators

The main losses of values in a tin concentrator are caused generally by the following:

1. Mining—drilling and blasting practices.
2. Mining—variation in ore characteristics.
3. Deficiencies in plant design, flowsheet and equipment.
4. Sliming in grinding and regrind mills.
5. Insufficient process control and poor overall operation.
6. Refractory tin constituents of the ore.

. Drilling and Blasting Practices

The processes of recovery of tin and ther economic minerals begin in the nine and are influenced by the mining perations and practices. Drilling and lasting techniques frequently give rise o overbreakage of cassiterite and also roduce primary slimes and fines of ther minerals. Possibly 2 to 3% of the in mineral, higher in some instances, nay consequently be already too fine n the mined ore to be effectively reovered in the concentrator. Adjustnents to the drilling pattern, drill hole izes, depths and spacings; quantities f explosives used, detonation sequences and other factors may be beneicial to plant operations. This may be ossible without incurring additional osts or problems in the mines and nay reduce overbreakage and the proluction of slimes. Primary slimes of ther minerals, if not removed from he feed and treated separately or disarded, may cause additional losses of alues by their effect on pulp viscosity, which should be minimised in all hases of gravity separation.

. Variations in Ore Characteristics

Possibly one of the major causes of ow tin recovery is the variable charac- er of the ore, extracted from different topes, levels and areas of the mine. The mine is usually concerned only with the production of a required tonage of ore for the mill and of a speific average grade. Rarely is any ttention paid to other ore characteristics which may influence plant operaion, process control and metallurgical erformance. These characteristics inlude hardness, amount and type of ssociated minerals, and the complexity f the tin-gangue associations; amount f sulphides and other critical mineral onstituents; slimes and oxide contents nd soluble salts. It is recognised that re blending from underground is usully difficult or, in some instances, imossible, also that the working of many nore stopes and levels may be impracical and more costly. Surface faciliies for this purpose may be a simpler nd more practical solution. Changes n ore characteristics are not always entirely recognised by the mill operators, and thus give rise to losses in production, spillages, reduced recoveries and poorer quality of concentrates.

3. Deficiencies in Plant Design, Flowsheet and Equipment

Most plants, especially those which have been in operation for a number of years, have undergone numerous circuit modifications and additions since they were built, in order to accommodate a series of progressive changes in ore characteristics or the demand for more throughput, to meet declining ore grade and rising costs, developed often from superficial metallurgical test work in the laboratory or plant. Often the original flowsheets are not a correct interpretation of the metallurgical process requirements, and the original process flowsheet and equipment may have been developed from testing either of a single composite sample or of a non-representative sample of the deposit. In some instances equipment is old, too small or not properly maintained, and this also creates problems of plant operation and affects metallurgical performance. Frequently, capital available for the design and construction of a plant is limited and unrealistic economies are sought by management and finance people to reduce capital costs by, for example, simplifying the flowsheet, installing smaller process units and not providing surge capacity between the various processing stages. Ore processing metallurgists are rarely determined or confident enough to resist these superior orders. Where increased throughput is required, feed preparation equipment such as screens and cyclones often become overloaded if not replaced or supplemented by larger or more units, and again the separation processes suffer.

4. Sliming in Grinding and Regrind Mills

The losses of tin from the plant are usually highest in the slimes and fines treatment sections of the plant. The major portion of these losses arise from overgrinding in primary, secondary or regrind mills, wherein the brittle cassiterite is selectively broken and is often present as free ultrafine particles in the tailing. Little or no feed rate control, poor sizing or classification ahead of grinding and in the preparation of feed ahead of a separation process may be largely responsible. Selection and operation of the grinding mills are also frequently unsatisfactory. In some plants regrinding of rougher concentrates, to liberate cassiterite from pyrite and arsenopyrite, causes overgrinding of cassiterite, which may then be mechanically entrained and lost in the froth in the subsequent flotation separation of the sulphides, even after several stages of cleaning.

5. Insufficient Process Control and Poor Plant Operation

The majority of gravity plants have few, if any, instruments or process control devices. A weightometer for measuring and recording plant ore feed tonnages; automatic mechanical samplers for cutting feed, concentrate and tailing streams. ammeters for indicating crusher and ball mill amperes and protective devices or malfunction alarms on crusher lubrication systems and ore conveyor emergency switches, and the like, are usually all the controls that a plant possesses. There are usually no means, other than visual or manual, for providing information about the process variables such as pulp flow rates, pulp densities, particle size analyses and actual plant stream assays. It is common practice to operate a

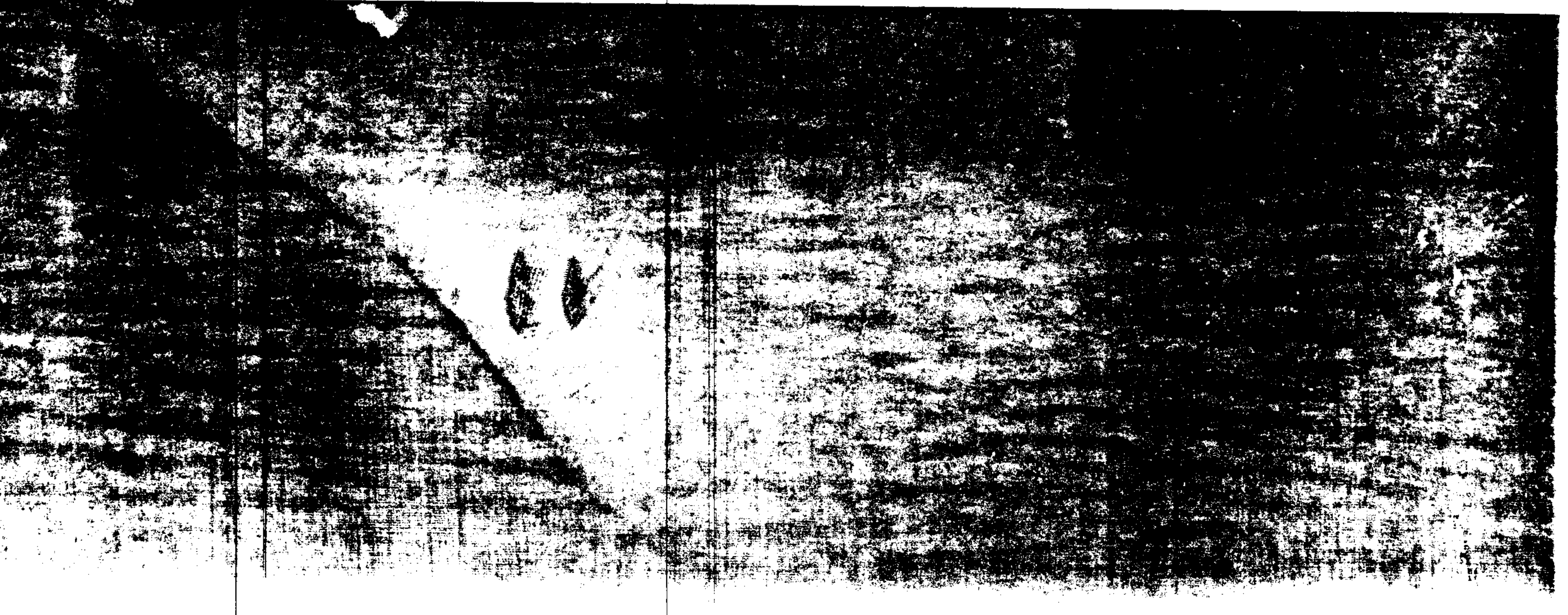
INTERNATIONAL TIN SYMPOSIUM

Representatives from tin-producing and consuming countries throughout the world met in La Paz, Bolivia, from November 14-21, 1977 for a week-long symposium on tin, in what was reportedly one of the largest gatherings concerned with the metal. Some 80 papers of engineering and economic importance were presented at the Bolivian symposium.

A number of papers were devoted to the economics of tin and covered projections of supply, demand and price, as well as the problems of substitution and stockpiling of tin. Technical papers dealt with geology, exploration, mining, beneficiation, smelting and refining of tin.

Bolivia is the second largest tin-producing country in the world and contains many mining and metallurgy facilities, field trips to some of the most important being part of the programme.

This article is a condensed version of one of the papers presented at La Paz. It is hoped that all of the technical papers presented will be published for international distribution both in Spanish and English. Interested parties should contact "The International Tin Symposium", Ministry of Mining and Metallurgy, Avenida 16 de Julio No. 1769, Cajon Postal, La Paz, Bolivia Q or: Resource Exploration International, 131 West 69th Street, New York, New York 10023, U.S.A.



plant to an acceptable mechanical or physical level, such that the process equipment is not visibly overloaded or underloaded and that there are no pulp spills or pipe blockages, etc. Little serious attention is paid generally to the correct operation of a plant from the process requirement viewpoints. Water additions are rarely measured or controlled and middling products are rarely constant in any characteristic such as volume, particle size, assay or pulp density. Surge capacity such as large dewatering classifiers, sumps, stirred tanks or thickeners are not found usually between the various unit processes and which would help control independently the pulp and solids flows and operation of each section. The fine or slimes section of the plant, in most cases, are fed from a thickener underflow but rarely is that thickener underflow volume or density adequately controlled. There are substantial difficulties in obtaining even modest recoveries and acceptable concentrate grades in the slimes section of the plant, under ideal conditions of operation, but this is almost invariably made more difficult by the lack of control of the feed pulp streams.

Plant operators are mostly conscientious and interested in their work but frequently lack training and sufficient understanding of their duties and responsibilities. They are often not fully aware of the basic requirements and purposes of the process and what the various machines do or their functions. This is not, incidentally, a criticism of the Bolivian worker as it is prevalent in many countries and industries. Mining companies, for many obvious reasons, however, do tend to attract a relatively poorer quality of labour. The increased involvement of labour in the operation and development of a mining entity is considered to be most important[26]. There are many other factors which affect the attitudes and interests of the mine labour force[29] which should be fully recognised. Kay[11] has suggested that operator capabilities have not kept up with process technology and the sophisticated equipment that is now available for ore processing.

3. Refractory Constituents of the Ore

Refractory features of a number of ores include finely disseminated or closely associated cassiterite in gangue or sulphides, and tin in forms other than cassiterite. Clearly where refractory tin minerals occur, they cannot be economically recovered by gravity processes or even by conventional flotation.

There does not seem to be any data available which provides a quantitative breakdown of the form, associations and liberation of the tin losses in the tailing products of plants in Bolivia, and for comparison, the form, association and grain size distribution of the tin minerals in the crushed ore fed to the plant. This data would provide a most valuable quantitative picture of how much overgrinding occurs, just how effective are the recovery processes[32], and would show the amounts and form of the refractory tin present. This article does not provide much encouragement toward the treatment of refractory tin ores, but it is not always apparent as to how much of the values lost in the plant tailings are in fact caused by the refractory nature of the ores. It is suggested that this may be shown to be much lower in many instances than is assumed.

Improvements to gravity plants

The scope and prospects for the introduction of new process equipment, additional or different feed preparation and auxiliary equipment, or for major flowsheet changes in an existing plant are excellent but may be somewhat limited because of the physical layout of the plant and by space restrictions. A thorough diagnosis should be made first, of course, of the whole plant process and equipment before any programme of test work and evaluation is undertaken. Mining, marketing and economic aspects which relate to or influence concentrator performance and profitability would be included in that study. Changes or additions that may be made would have to be fully justified in economic as well as in practical terms and their implementation and success assured before they were actually made.

A process flowsheet is an integrated system and the performance or efficiency of each machine or section is influenced by the processes and equipment that precede it, and follow it, where middling recycling is practised. Changes in the mine and in the initial stages of a process could therefore have significant effects on subsequent sections of the plant. These must be kept in mind in the analysis of an operation. The aspects of a plant which might give the quickest and most significant improvements in recovery and profitability may be, in order of priority:

(1) Improvement or expansion of ore storage and blending facilities on the surface ahead of processing;

(2) The installation of a thickener or thickeners ahead of both the fine sand and the slimes sections of the plant, with effective control of thickener underflows to the process;

(3) The introduction of on-stream analysis systems for continuous monitoring of each tailing stream, if practical, and of the feed pulps to each section of the plant, particularly the fine sands and slimes. The introduction of other key process control or measuring devices may also be advantageous;

(4) Improvements where possible to the feed preparation systems ahead of the separation processes, especially in the fine sand and slimes circuits;

(5) Improvements, as applicable, to the primary grinding and regrind units in an attempt to reduce overbreakage.

The introduction of new process equipment, such as spirals, cones, Bartles-Mozley or Crossbelt separators may be possible and these are discussed briefly later, and elsewhere[2].

The full cooperation of mill management and senior company management in making the studies and changes to the plant is important and the programme should be initiated, supported and directed with the involvement of the plant and operations managers. This is essential to the success of the project, as too often personal pride or jealousy may prevent or limit the effectiveness of the improvements that could otherwise be made. Changes made in a plant, with outsider assistance resulting in improved recovery may frequently be interpreted as a reflection of the incompetence or laziness of the mill manager. This is not, of course, the attitude or the assumption made by enlightened management or mature technical and operations staff and should not be so construed or implied.

The training, understanding, cooperation and involvement of the plant labour force are also essential to any programme of concentrator improvement and this cannot be over-emphasised. Cooperation between the various operations personnel and outside services, manufacturers, and specialists that may be used, is also of primary importance.

Design of new gravity concentrators

Traditionally, gravity plants and other types of concentrators have been designed mostly on the basis of individual experience of one or a few persons and the experiences of the local or at best national industry. This can no longer be justified or accepted and the widest possible knowledge and experience available world wide must be sought and fully utilised. The basis for the design of a plant[1] is the testing of representative ore samples, in the laboratory and possibly also from full or partial scale plant tests. Too often the sample or samples tested do not represent the orebody and insufficient consideration is given to the variability of the ore. It is not unusual that good samples are not available

...on needed for testing and for the ...duling of the essential phases of ...nt design. This is sometimes ex... ...ned by the limitation of funds for ...ving a development tunnel to secure ...able bulk samples or to inadequate ...ect time-tabling. Even where pro... ...t management is aware of the impor... ...ce of testing of adequate samples, ...type of deposit may not permit the ...opment of the mine and the open... ...up of too many levels or areas of ...mine initially to get those samples. ...k samples from the first sections of ...orebody to be mined, plus core ...ples from other levels or zones, ...uld be more than adequate nor... ...lly for process testing and for flow... ...et development. Sufficient flexibility ...uld be built into the plant design ...way and generous oversizing of key ...cess, feed preparation and materials ...ndling equipment is important. The ...rect technical and economic inter... ...tation of test data is also important ...t often difficult to implement fully. ...ten these decisions are made, based ... mature judgment and experience in ...s field and by a number of experi... ...ced people. The test work itself must ... performed carefully, thoroughly and ...der realistic conditions. The rela... ...onships among size distributions, tin ...covery and concentrate grades for ...ch proposed section of the process ...ould be known from the test work. ...omprehensive pilot scale test work ...ay be limited, or unjustified—cer... ...inly for smaller plants—but individual ...nit processes such as grinding, classi... ...ation, dense media separation, cone, ...iral and tabling tests may be made, ...d often are provided as a service ... equipment manufacturers, if not ...ailable within the country.

...ommunication

Close communication and coopera... ...on between the exploration geologists, ...ine planning engineers, mineralogists, ...boratory and plant metallurgists and ...thers are important at different phases ... the scheduling and execution of all ... the metallurgical test work required ...r development of the final process ...owsheets. Preliminary engineering ...d capital cost estimates and economic ...nalyses may be made as the test work ...evelops. A thorough knowledge of the ...ineralogy of the orebody and its ...ariations, important to the processes ...d treatment of the ore, is also neces... ...ry before any serious test work is ...ndertaken[32]. A knowledge of the ...aracteristics of the plant products is ...so important to plant design.

Once the process flowsheet has been ...ecided, the final engineering design ... the plant can begin. Again, close ...aison is most important at this stage ...d as the project progresses, among ...e process and plant metallurgists, mill manager and maintenance staff, mining staff, the various design engineers, economists, finance personnel, marketing staff and senior management. This is necessary to ensure that the best interpretation of the process flowsheet is made and to give ultimately a practical and smooth operation and a plant capable of efficient and economic treatment of the ore with minimal difficulties from start-up.

Cost considerations

The control and minimisation of capital cost is of course important and several trial layouts and rough cost estimates may be needed, but may only be justifiable for plants of about 1000 ton/day or more capacity. Examples may include a comparison of single deck with triple deck tables or of the layout of spirals versus shaking tables for coarse sands or jigs versus dense medium separation. Operating cost comparisons would also be made and the effects on the rest of the process may be assessed. Installed costs may be substantially higher for single deck tables because of the greater space requirements and extra foundations and for construction costs plus the extensive piping and pumping systems for handling the products. For coarse sand roughing however single deck tables may be more efficient and give higher recoveries. Installed cost comparisons and metallurgical performance between similar machines of different manufacture may also be made and available technical services, parts costs, ease of maintenance and operation, also considered in the selection of equipment. Initial cost should not be the major factor in the selection of process or other equipment.

Minimisation of capital costs, while important, because of the obvious financial constraints that are usually imposed, should not be made however at the expense of the metallurgical efficiency or adequacy of the overall design. Operating costs are especially important now with the present world inflationary trends and should be properly recognised in the design phases of the plant. With the high price of tin, it can be readily shown that substantial capital expenditure and more sophisticated design of a plant can be justified to achieve the highest practical economic recovery into a product or products of good marketable grade and quality. An economic model relating, for example capital costs, operating costs, estimated recoveries and concentrate grades for several sizes and design layouts of plant can probably be justified, but only for larger plants, to focus on and establish the optimum combination for a given orebody and grade of ore. A more comprehensive economic model, incorporating the major parameters for [illegible] analysis [illegible] also be made for the project overall to include also the mine, ore grade, metal price and for different methods of financing, etc.

Some seemingly minor aspects of new plant design may perhaps be ignored for the present in Bolivia, but they could be important later or even now in some cases, and should be incorporated into the design. These include conservation of power and energy requirements; ecological control, such as from pollution from plant effluents, and minimisation of labour required for operation and maintenance purposes. Smaller capacity plants cannot justify usually the costs of these engineering studies and are designed to ensure maximum operational flexibility based on sound test work, with the equipment generously oversized.

Two aspects of ore blending and storage may be considered where regular methods cannot be applied. Firstly, the recycling of the major part of the crushed feed back to the fine ore bins, in order to minimise size segregation and variation in the plant feed[33]. A fixed part of the crushed feed as required may be cut from the bin feed belt, using a rotary type sample splitter and fed by conveyor into the processing plant. The remainder would be recirculated back into the fine ore bins using two conveyors designed and installed in a scissor-type arrangement. The second possibility is to screen the crushed ore into separate bins for storage and blending purposes and to feed each size of material independently into the plant. This would allow better control of the size make-up of the feed into the plant and could be realistic perhaps for a concentrator where jigs are used for preconcentration of the ore, and where the different sized feeds enter different jigs arranged in parallel. The advantage would be that the jigs would perform more efficiently with a more controlled feed compared with the current practice of preparing the total feed from the fine ore bins, ahead of the jigs, by wet screening and regulating only the total feel tonnage to the wet screen. By this practice, variations in the size distribution of the crushed ore, which will occur as the bin is emptied or filled will be reduced, with consequent beneficial effects on jig performance and also provide a more uniform feed to the rest of the plant.

Wet crushing plants offer a number of advantages over the conventional practices[30]. A wet crushing plant may involve wet screening, or scrubbing in a drum type vessel, of primary crushed product, to remove primary slimes and fines. Those fines ($-\frac{1}{4}$in) may be dewatered by further screening or spiral classifier and the coarse product (+48 or 65 mesh) added to the final crushed [illegible] may then be thickened, with or without cycloning, and fed from there to a separate section of the plant for tin recovery. The scrubbed coarse ore may be further wet screened after the secondary crushing stage and those fines added also to the primary fines system, but usually this is not necessary. The crushers themselves would be of the conventional jaw and cone types. Dusting would be eliminated and hence the need for a dust collection system. Primary clays, oxides, and other gangue fines, which may create crushing and handling difficulties would be isolated and eliminated early from the crushing system. Soluble salts would also be removed, if present, from the main process plant.

The top size of run-of-mine ore must be known or estimated, of course, for the crushing plant to be designed. The optimum top size of the mine ore would perhaps be determined finally however only after the plant and mine are in production. The costs of breakage of the ore during mining and in transferring it, through ore passes, pockets, loaders and transport system into the mine ore bins, would be compared with the costs of crushing of the ore from coarser or finer sizes. The aspects of overbreakage of mineral values have already been discussed and should also be considered here. This would probably favour overall, that most ore breakage take place in the crushing plant, provided the mining system and equipment could effectively handle the coarsest size of ore.

As the grinding sections of the plant are likely to contribute substantially to the losses in the slimes through overbreakage, careful attention must be given to this in the design stage. Slow speed short length ball mills with grate discharge for primary grinding have been successfully employed. Removal of fines ahead of the mill is also important by use of a stationary wedge wire screen, or a multifeed point vibrating screen, with polyurethane wedge wire surfaces. Grinding mills are not employed to reduce the size of the ore *per se* but to bring about effective liberation of the tin mineral with minimal overbreakage of the free values or of free gangue. This is not always understood by design engineers or equipment manufacturers in particular.

Too often one mill only is included in the flowsheet and the ore ground, in closed circuit, to the fineness necessary to liberate all values. The primary circuit may include a unit jig or scalping table to recover liberated values in the mill discharge. Several stages of grinding can be economically justified if the ore mineralogy and tin distribution so require them. Insufficient attention is given also to liner contour or to the control of ball size and volume of the charge in these mills. Sizing of the primary feed and grinding in separate mills of different diameters and with different ball charges might be justified in some instances. It is not acceptable from a process viewpoint to select a mill simply on a horsepower basis and leave the mill dimension and specifications to the design engineers to decide. Large mill circulating loads, through a screen, should be provided for in the design and variable speed mills can be installed, to allow for extra flexibility with regard to throughput. For the present at least the equipment industry has nothing better to offer for comminution below about $\frac{1}{4}$ in than rod or ball mills. Some possible new concepts and mill designs are discussed later.

The provision of an adequate and flexible pumping system including good sump and pump box design, to transport the feeds and products to subsequent stages of the process are important to good design. An effective and reliable pulp distribution system to feed individual tables, spirals and cones in their respective sections is also critical. The removal of any and all foreign matter from the ore and pulp streams and also from fresh and recycled process water supplies is important. Spray water to screens and wash water to tables and spiral concentrators, etc., is essential for efficient separation and must be free of solids and trash at all times.

The potential benefits and usefulness of instrumentation in new concentrator design is even greater than for existing plants, as the design can be arranged better to accommodate the sensors, measuring and recording devices and the mini-computers which may be integrated with them. A more logical and suitable overall control system can also be designed more effectively and simply for a new plant. Early experiences with process control systems were generally [illegible] but in the past 5 years or so, more reliable sensors and solid state controllers have become available and mini-computers of the digital type have become more compact and dependable and are of relatively low price[36, 37].

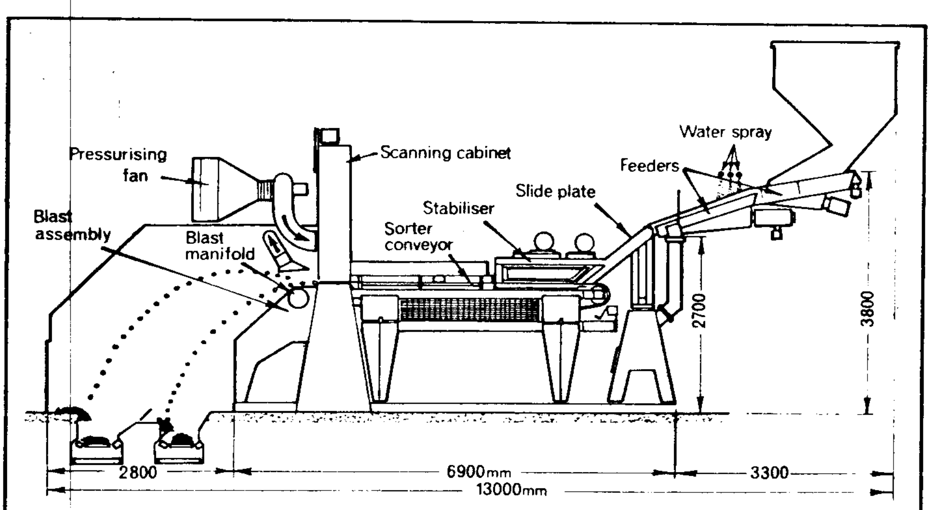
Good basic process data must be measured and recorded to provide information for plant operation and records and for analysis for management and for plant diagnostic studies. On-stream analysis even for small plants, at least of feed and tailing streams is considered to be essential and unquestionably can be justified in real economic terms.

With the technology now available and used properly very much more efficient operations can be achieved in gravity concentrators and these can help hold down capital costs and operating costs and in many instances permit the economic exploitation of what were previously uneconomic or marginal deposits. Profits should also be possible in well designed and operated plants even with much lower tin prices than those currently being enjoyed.

Equipment advances

Developments in separation and other process equipment are outlined briefly below, together with interesting factors relating to the fabrication and materials now used. Some aspects of process control systems are also given which should have immediate economic application to the processing of Bolivian tin ores, as well as of tungsten and other heavy minerals concentrated by gravity processes. Other data are given (references 2, 9, 19, 34).

IHC—Jig. IHC has developed an improved jigging cycle where the bed motion is of a sawtooth profile with a rapid upward stroke and a slow downward stroke. The mechanisms developed to provide this stroke pattern are mechanical, mechanical-hydraulic or



The model 16 photometric sorter from Ore Sorters Ltd. (Rio Tinto and Gold Fields). (all dimensions in mm).

fully hydraulic. The mechanism selected depends on a number of factors which include the number of hutches, plant maintenance skills available, purpose of the jigging plant and the flexibility in operation that is required. The IHC jigs use considerably less power, and little or no hutch water, and considerable improvement in the recovery of fine heavy minerals can be obtained.

Dyna Whirlpool Process (DWP). Two main types of dense media separator are currently used—the static type, typified by cone and drum separators and the dynamic type—of which the cyclone and the Dyna-Whirlpool process are the principal systems[24, 35]. The Dyna Whirlpool process was developed originally for coal washing but has since found extensive actual and potential applications in the treatment of non-metallic minerals, such as fluorspar, and more recently for the preconcentration of base metal ores, tin and tungsten ores, and various coarse tailing and waste piles, containing a variety of economic mineral values. Reportedly, a two-stage DWP plant will be installed shortly in Bolivia for preconcentration of a tungsten ore.

The prepared feed, up to 25 to 30 mm top size, containing particles possibly down to about 20 mesh, is fed into the top of the DWP vessel, together with some of the heavy medium, usually fine magnetite or ferrosilicon or a mixture of the two, according to the density of medium required for optimum economic separation. The centrifugal forces generated by the medium, which is pumped tangentially into the vessel through an inlet pipe near the lower end of the separator, cause the heavy mineral particles to be forced towards the wall of the vessel, and these are removed as the "sink" product through a tangential pipe located near the top of the cylindrical section, together with a portion of the medium.

The light minerals are carried downwards in the inner section of the separator and are discharged at the bottom of the vessel, also with medium, as the "float" product.

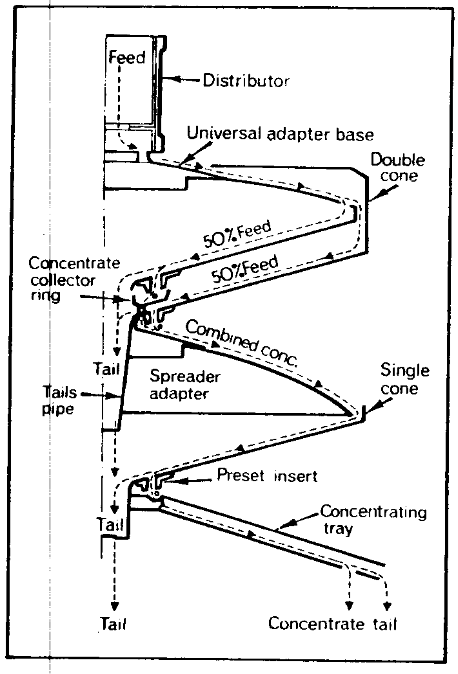
In the treatment of ores containing high value minerals, such as tin and tungsten, it is considered advisable to use a two-stage DWP system, wherein the tailing product from the first separator vessel is retreated in the second DWP unit. This arrangement protects the operation from serious losses of values into the float product, through poor operation, such as a high density medium or a medium with temporary high viscosity or from poorly prepared feed, for examples.

Photometric Sorting. Where water may be in short supply or where differences in density between the mineralised rock and wall rock are not sufficient to employ dense medium separation, applications may exist for colorimeter sorting. Sophisticated systems are available from Ore Sorters Ltd.[14] and from Gunsons Sortex[22], and the most economic applications are where either the gangue or the economic minerals are essentially liberated at sizes coarser than ½ in (12 mm).

The model 16 photometric sorter of Ore Sorters Ltd. comprises a surge bin into which the crushed and screened ore is deposited. A primary vibratory feeder transports the rock pieces to a secondary feeder, where, after spray washing to enhance reflectivity, the material is transferred onto a slow speed flat conveyor, where the ore pieces are scanned optically, every 2 mm, by a laser-rotating mirror-photomultiplier assembly. The photomultiplier signals the reflectance level of each rock piece to an electronic processor which computes the size and position and decides whether to accept or reject the particle. Beyond the scanning zone, and at the end of the conveyor, the rock pieces pass over an air blast manifold connected through solenoid valves to a high pressure (700 kPA) air supply. The electronic processor activates the appropriate air valves to divert the selected rock pieces out of their normal fall trajectory onto a separate conveyor. The model 16 Photometric Sorter is illustrated.

Reichert Cone Concentrator. The Reichert concentrator was developed in Australia by Mineral Deposits Ltd. as a high capacity, preconcentration device, as well as for secondary and tertiary upgrading, for the economic separation of rutile, zircon and ilmenite from beach sands[1]. This is a separator of the flowing film type related to the pinched sluice concentrator and has been applied successfully in the mineral sand industry in Australia in plants of up to 1500 ton/h capacity. Other successful and more recent applications have been in the preconcentration of tin ores in grinding circuits, scavenging of uranium and zirconium minerals from flotation tailing and in the concentration of a magnetite ore[10, 16, 18, 19]. Material in the size range of about 1 mm down to 270 mesh can be effectively upgraded, but in some instances the size range can be extended from 3 mm down to 30 microns.

The basic separation unit in the cone concentrator is an inward sloping (17°) cone of 2 m diameter made of fibreglass. Single and double cones are used and a number of units are assembled into a single concentrator assembly, and with a configuration best suited to the material to be treated and the particular application. A typical stage configuration is illustrated. Two other configurations, of the many available systems, incorporated into complete cone units are shown (p. 43).



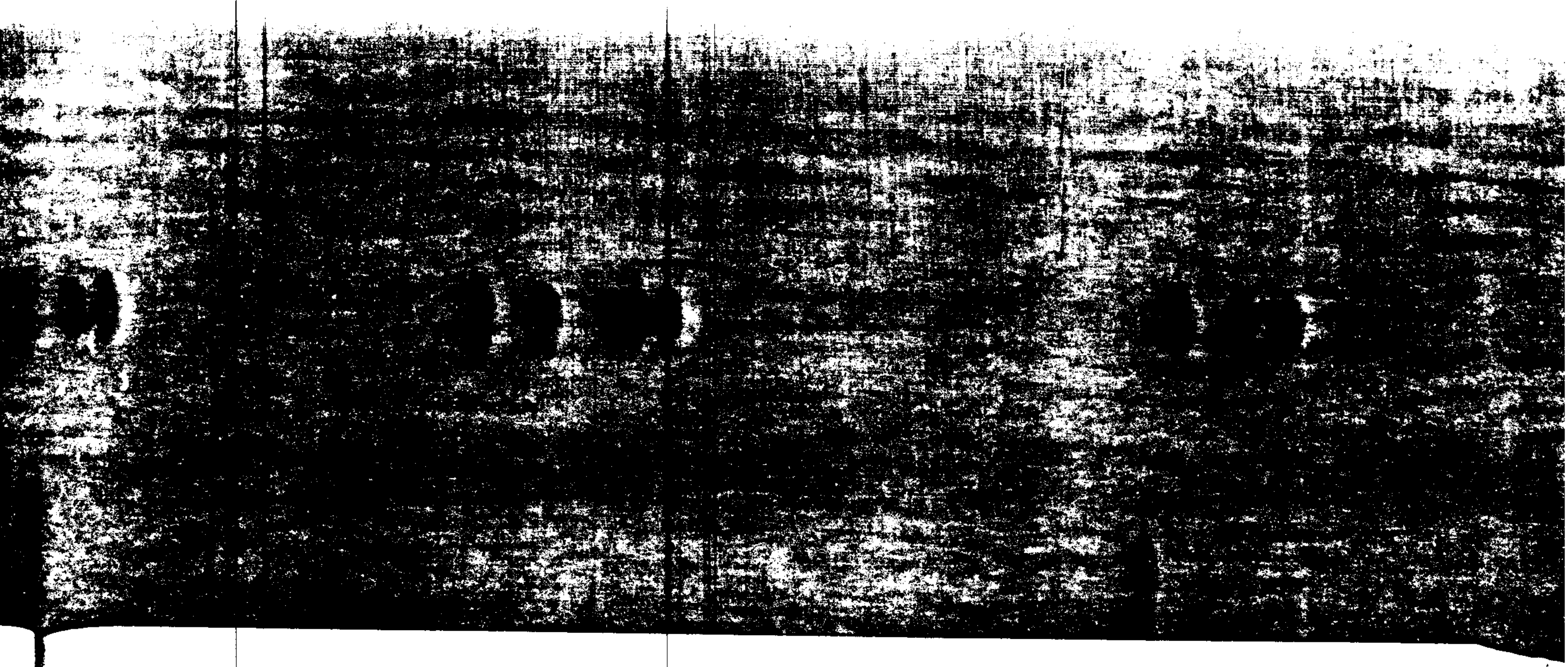
Reichert cone concentrator. Typical stage configuration comprising a double and a single cone. (Mineral Deposits Ltd., Australia).

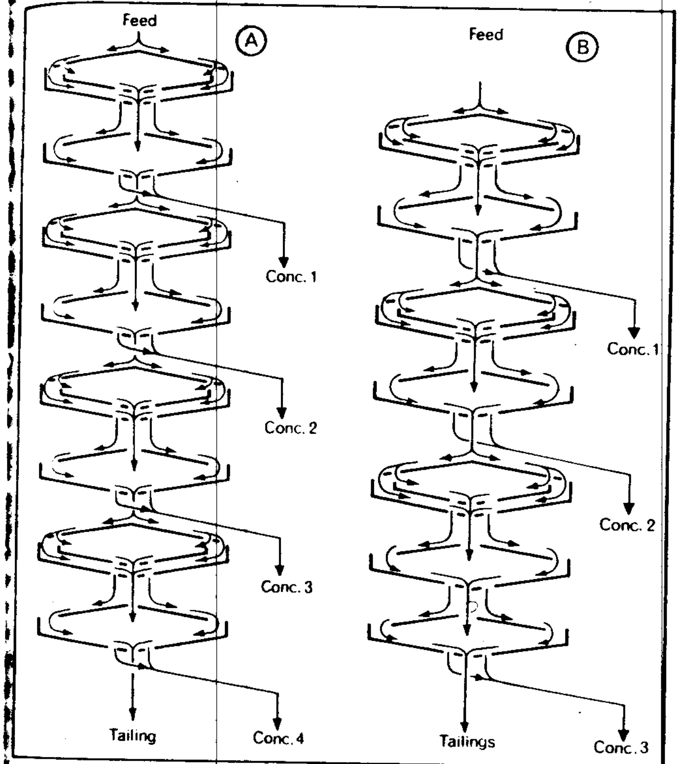
Bartles-Mozley Table and Bartles Cross Belt Separator. The greatest need in gravity treatment of fine mineral particles of below about 30 microns has been for an efficient, high capacity machine that is relatively inexpensive and simple to operate and control. Some success has been achieved by the Bartles-Mozley Table, which has been described in various papers[6] and there are already a number of units installed in various plants in Bolivia. The Cross Belt separator (*Mining Mag.*, December 1977, p. 631) which is basically a development of the Vanner, using the Bartles-Mozley Table drive mechanism is capable of handling deslimed feed in the size range of about 5 to 100 microns. This machine has also been described elsewhere[17].

Other equipment and fabrication materials

There have been numerous new developments in other process equipment, and in materials used for their manufacture. Mobile crushers assembled in modular units are available incorporating small surge bins, feeders, primary and secondary crushers, screen and conveyors, built, to suit a particular application, into one or more mobile modules.

Resin bonded fibreglass is being used for shaking table decks as well as for spiral and cone concentrator surfaces and for BM Table decks. Polyurethane is finding many uses where light weight and/or abrasion resistance are important. The ERWO grinding mill with spiral liner configuration developed in





Reichert cone concentrator arrangements. A. Internal flow configuration type 4DS. B. Internal flow configuration type 2DS DSS. (Mineral Deposits Ltd.).

Austria has attracted considerable attention and a unit is being tested at Catavi, Bolivia.

The application of dry autogenous or semi-autogenous grinding to the comminution of tin ores has been tested on a pilot scale but there have been no actual plant size mills installed. Wet or dry vibratory mills for grinding of middling products or of low grade concentrates, prior to further upgrading processes have not been applied apparently to tin ore processing, but with control of ball size and the vibration amplitudes, vibratory ball milling could help reduce overgrinding of cassiterite and other brittle minerals, in middling circuits and for upgrading of rougher or intermediate concentrates.

There are a number of belt type vacuum filters offered which could be readily applied to dewatering of coarse and of fine tin concentrates, especially since they contain only limited amounts of slimes. New devices for thickening of tailing and middling products or concentrates include the Lamella thickener [30] and the Enviro-Clear thickener [38].

The Wyssmont turbo-dryer is a multiple tray machine for handling especially fine tin concentrates and a variety of other fine products and chemicals, with minimal or negligible dust losses.

On-stream analysis and computer control

A paper describing the system installed at Geevor in Cornwall [4] is of interest. The Geevor on-stream analytical system comprises combined X-ray fluorescence and gamma-ray sensors for monitoring the tin and solids contents of the three plant tailing streams (coarse sands, fine sands and slimes) and for the three primary mill feed streams. This system has proved to be sufficiently reliable that regular assays of tailing streams have been discontinued and similar action regarding feed assays will shortly be taken.

Conclusions

The scope for improvement in gravity concentrator performance in existing plants and in the design of new plants is extensive. There can be little doubt that there is a great deal that might be achieved; this can and should be pursued urgently.

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