The gravity recovery of cassiterite*

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SYNOPSIS

Cassiterite is considered to be the only economically significant tin mineral in the earth's crust. In its purest form, cassiterite contains 76 per cent tin. The mineral is hard and heavy but also extremely brittle, and is therefore ideally suited to gravity recovery techniques.

Cassiterite deposits can be categorized into two main types, i.e. alluvial or 'soft' rock deposits, and 'hard' rock deposits. The former are relatively simple to upgrade owing to their relatively coarse nature and their high degree of liberation. Hard-rock deposits, on the other hand, require considerably more sophisticated gravity methods to achieve the required degree of beneficiation.

Various types of gravity recovery devices, both old and new, are described, and their respective roles in the flow-sheets used are illustrated.

SAMEVATTING

Kassiteriet word beskou as die enigste ekonomiese belangrike tinmineraal in die aardkors. In sy suiwerste vorm bevat kassiteriet 76 per sent tin. Die mineraal is hard en swaar maar ook uiters bros en dus besonder geskik vir swaartekragherwinningstegnieke.

Kassiterietafsettings kan in twee hoofsoorte ingedeel word, d.w.s. alluviale of 'sagte' rotsafsettings en 'harde' rotsafsettings. Eersgenoemde is betreklik eenvoudig om op te gradeer vanweë die betreklik growwe aard daarvan en hul hoë mate van bevryding. Aan die ander kant vereis die harde rotsafsettings heelwat meer gesofistikeerde swaartekragmetodes om die vereiste graad van veredeling te verkry.

Verskeie soorte swaartekragherwinningstoestelle, oud en nuut, word beskryf en hul onderskeie rolle in die vloeidiagramme wat gebruik word, word geïllustreer.

Introduction

Cassiterite (SnO_2), otherwise known as tinstone, is the only tin mineral that is in sufficient abundance in the earth's crust to have any commercial value. When chemically pure, which is rare, cassiterite contains 78,6 per cent tin but, when contaminated with impurities, the tin content varies between 73 and 75 per cent.

The main commercial tinfields of the world are as follows: West of England, Brittany, and Erzgeburge; Burma, Siam, Malay States, and Indonesia; Bolivia; Nigeria; Australasia; and Southern Africa.

Cassiterite is mainly found in two types of deposits. In the first, it occurs as a primary accessory constituent of certain late-stage granitic intrusions, and is found in veins and fissures both in the granite and surrounding country rock. The second type of deposit is of a secondary origin and occurs as alluvial or placer and detrital deposits.

There is a clear association of cassiterite with highly acidic granitic rocks, and it is an interesting and significant fact that at not a single tinfield in the world has cassiterite been found *in situ* except near granite or granite rocks. Because cassiterite is a chemically stable mineral, each type of primary deposit contributes to the secondary accumulations that are at present the major source of tin.

The bulk of the world's supply of cassiterite comes from stanniferous alluvial deposits derived from mineralized areas in their neighbourhood. The main source of tin in South Africa is to be found in the northern Transvaal, where deposits of the Rooiberg, Leeupoort, and Union Tin regions occur in arkosites and shales of the Precambrian Transvaal System, which in this area forms a roof-pendant of the 2000 Ma Bushveld granite.

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Gravity Recovery of Cassiterite

It is obvious from the physical characteristics of cassiterite that its high relative density in relation to its gangue constituents makes it an ideal mineral for the application of gravity-separation techniques. Unfortunately, its relative hardness – approximately equal to that of steel – is accompanied by the unfortunate quality of extreme brittleness. This factor must be taken into account during the crushing and grinding operations prior to concentration, and leads to the general policy that cassiterite grains should, where possible, be recovered at the earliest possible stage and at their largest size. Once the particles have been reduced in size to below about 43 μm, the efficiency of gravity-concentration processes decreases markedly.

The gravity techniques applied to the recovery of cassiterite basically fall into two categories: those applied to soft-rock, and those to hard-rock deposits.

Soft-rock Deposits

This category includes mainly alluvial deposits, which account for 70 to 80 per cent of the world reserves, and the beneficiation processes are relatively simple because of the high degree of liberation of the particles.

For alluvial deposits, the simplest and probably the earliest method of recovery and concentration was by means of panning and other hand-washing devices. On average, a worker using this method could treat about 1 m^3 of material in 8 hours. An early example of natural sluicing action comes from the early Cornish operators, who would wander along the beaches looking for areas where the heavy minerals had been concentrated by tidal action. To enhance this process, they supplied riffles in the form of strong boards anchored in the sand parallel to the waves. The action of the tide would concentrate the heavy minerals behind these boards.

The basic commercial method of primary concentration is the sluice box used on alluvial deposits in Malaysia and Thailand, known as palongs. The palong is essentially a wooden sluice box divided into longitudinal compartments or lanes, and normally constructed on a sand bank for support. Most palongs have between 4 to 8 lanes, each of which is about 2 m wide and 44 to 60 m long, the preferred length being 49 m. On average, each palong lane is designed to treat between 135 and 170 m³/h of feed slurry. The concentrate so derived contains about 15 to 30 per cent tin and the recovery efficiency can be up to 80 per cent. The palongs lose efficiency when treating particles less than about 100 μm in size.

The palong concentrates are dressed either manually or by the use of jigs. The manual method, which consists of countless cycles of hydraulic classification and sluicing, is not only labour-intensive, but the treatment of new feed comes to a virtual standstill during this operation as all the workers are required for the cleaning operation. As a result of this, it is now estimated that about 40 per cent of the Malayan gravel-pump mines use jigs for the cleaning operation. The final concentrate leaving the tin shed contains 75 to 76 per cent tin.

Where the recovery of cassiterite is by dredging, the difficulty encountered is not so much in the raising of the material but in its subsequent treatment, since the working area on the dredges can be very limited. Consequently, jigs are the favoured method of concentration. An attractive feature of jigs is their ability to accept a wide variation in feed rate and still produce concentrates as high as 20 to 30 per cent tin.

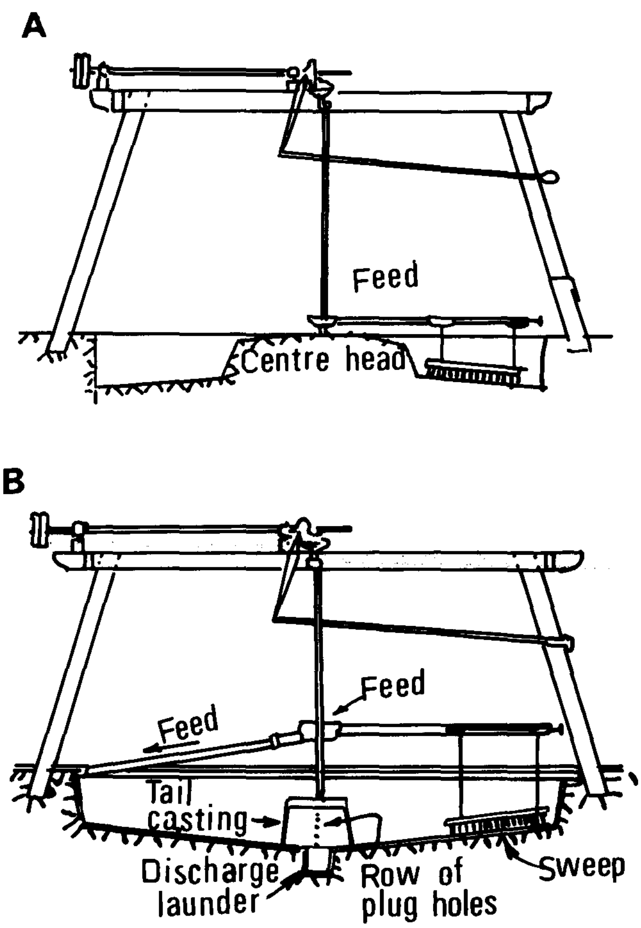

Fig. 1—A schematic diagram of a convex buddle (A) and a concave buddle (B) — after Truscott

Hard-rock Deposits

For hard-rock ores, liberation of the cassiterite from the associated gangue minerals is achieved by conventional crushing and grinding. However, because of cassiterite's extreme brittleness, significant quantities of very fine particles can be produced at this stage, resulting in losses of tin in the succeeding processing stages. It is pertinent to mention that froth flotation, which is used to upgrade particles less than 43 μm, is not able to treat particles smaller than 6 μm in size. In some cases, the unrecoverable minus 6 μm cassiterite can account for as much as 6 per cent of the metallic tin entering the plant.

Most hard-rock tin concentrators use different combinations of the same crushing and milling equipment to effect the liberation, which are then followed by a wide variety of gravity-concentration devices for further beneficiation. The plant at Rooiberg Tin Mine illustrates these methods.

Rooiberg Tin Mine

Rooiberg is the largest producer of tin in South Africa, and the present company has been in operation since 1905. However, it is known that mining and smelting operations were being practised at Rooiberg at least 500 years ago by people as yet unidentified by archaeologists.

Buddles and Round Frames

The original plant at Rooiberg was designed and operated by Cornish engineers. The flowsheet of the mill in those days showed that the sulphides and other heavy minerals were removed from the concentrate by calcining, buddling, and tossing in Kiev tubs. As none of these processes is suitable for coarse concentrates, no attempt was made to recover the mineral as soon as it was liberated.

A schematic layout of concave and convex buddles is shown in Fig. 1.

The round frame and Acme frame were developments of the buddle, and all operated on the principles of the flowing film separator.

Tossing of the tin concentrates was usually the last upgrading stage in the recovery programme. This consisted of swirling and agitating the concentrate in a Kiev tub. The heavy mineral moved to the side of the tub and downwards, and the lighter gangue formed a core in the centre. The sides of the tub were rapped vigorously during this process to aid the stratification.

Some of these methods of concentration remained in use at Rooiberg until the mid 1970s, although coarse grinding and slime removal by hydrocyclones were first introduced in 1949.

The present-day operations are divided into two sections, i.e. the Rooiberg and the Leeuwpoort Mines, which are situated some 20 km apart. The concentrators at each section employ the same basic principles and each treats about 20 kt of ore per month. The head grade of the ore varies between about 0,5 and 0,7 per cent tin, but at times has exceeded 1 per cent. The Leeuwpoort (C Mine) ore is coarser, and is more easily liberated than that found at Rooiberg (A Mine).

Heavy-medium Separation

The initial stage of the operations involves crushing of the run-of-mine ore to a size suitable for the first stage

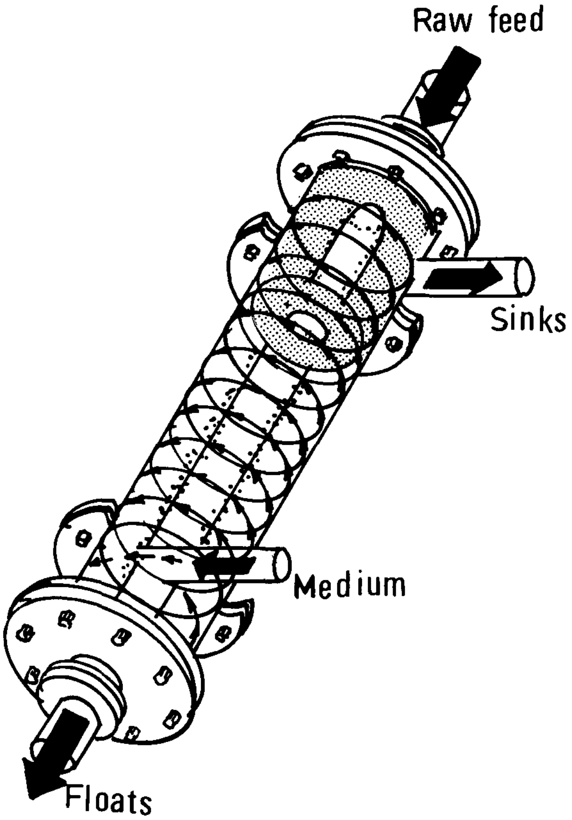

Fig. 2—A Dynawhirlpool dense-medium separator

of gravity separation (12 mm), which is a heavy-medium process using a Dynawhirlpool separator (Fig. 2). The operation at C Mine differs slightly from that of the A Mine at this point in that, because of the presence of larger crystals of cassiterite, a jig is incorporated in the crusher circuit to concentrate any minus 3 mm material entering the plant. The jig concentrate, which has a grade of 30 per cent tin, accounts for about 2 per cent of the total production of tin from this plant.

The Dynawhirlpool separators in both Rooiberg concentrators are 310 mm in diameter and treat material in the size range minus 12 mm plus 1 mm. This operation discards some 66 per cent of the total ore entering the plant and recovers 85 per cent of the tin. The relative density of separation is about 2,9, and the medium used is 100 D ferrosilicon (Table I). The consumption of ferrosilicon is about 300 g/t, and the cost of the heavy-medium process is at present 80c per ton of material treated.

Up to 1979 it was standard practice in heavy-medium separation plants to screen the feed at a size of about 0,5 to 1 mm, and feed only the oversize into the separating vessel. The fines were then treated by some other conventional system, which at Rooiberg was a combination of jigs and shaking tables. Development work at the Fuel Research Institute led to a system for the treatment of minus 0,5 mm coal by heavy-medium techniques. Further development at the Gold Fields Laboratory in conjunction with Nortons Tividale showed that this system could also be applied to tin ore and, as a result, a fines-treatment plant designed around a 125 mm DSM (Dutch State Mines) cyclone was built at the C Mine in 1980.

The results to date indicate that 95 per cent of the tin is concentrated into 35 per cent (by mass) of the feed. The heavy medium used is a mixture of 100 D ferrosilicon and magnetite – the latter being used to stabilize the medium. Losses of heavy medium are higher than that experienced in the coarser heavy-medium circuit, and are about 1,3 kg/t.

Although Dynawhirlpool units are used for primary separation at Rooiberg, other units such as cyclones, drums, and cones (as used in Cornwall) may be just as efficient. However, it would be expected that drums and cones would be more suitable for the beneficiation of larger particles of cassiterite.

Considerable experimentation was carried out in Cornwall on the use of heavy liquids for gravity separation. The liquid used was tetrabromoethane, but the process was not economically successful owing to the high losses (by adherence) of this expensive liquid.

Shaking Tables

The sink concentrates arising from the heavy-medium separation, which contain some 2 to 3 per cent tin, go forward to milling and tabling. In order to minimize the production of minus 43 μm particles, this part of the beneficiation process takes place in stages, and a circuit consisting of stage grinding with intermediate gravity recovery using conventional shaking tables is therefore used.

Each mill product is classified into narrow size ranges by the use of hydrosizers before table treatment. In the concentrator at Rooiberg, 3 'lines' of tables are used, preceded by rod milling in the first instance and followed by 2 stages of ball milling. The size grading of the feed to each of the lines of tables is shown in Table II.

Table III shows the sizing effect of the hydrosizer operating ahead of the first line of tables. Hydrosizers serving the second and third lines of tables achieve similar splits, but in each successive line the feed is finer, as shown in Table II.

TABLE I

SIZE ANALYSIS OF 100D FERROSILICON

Mesh size	Mass, %
48	0,1
100	0,6
200	19,4
+325	37,9
−325	42,0

TABLE II

THE GRADING OF THE FEED TO THE LINES OF TABLES

Size mesh	Line, % (by mass)		
	1	2	3
+28	5,1	0,2	—
+48	20,1	4,5	1,0
+100	33,3	30,0	3,4
+200	29,1	44,1	11,3
+325	9,3	15,9	45,5
−325	3,1	5,0	38,8

TABLE III

SIZING OF THE HYDROSIZER

Size mesh	Spigot, % (by mass)					
	1	2	3	4	5	6
+28	13,5	13,4	6,7	4,7	3,2	1,0
+48	32,0	32,3	28,5	31,3	21,1	8,0
+100	30,1	31,6	32,8	35,0	41,4	43,0
+200	17,0	17,8	24,0	23,0	27,6	39,2
+325	5,3	3,7	6,8	5,5	5,3	8,0
−325	2,1	1,3	1,2	0,5	1,4	0,7

The concentrate from each series of tables, which has a grade of between 12 and 20 per cent tin, goes forward to the concentrate-dressing section. These concentrates represent about 3 per cent (by mass) of the original feed to the tables.

The overflow from the hydrosizers, containing most of the minus 43 μm particles, is routed to the flotation section for desliming at 6 μm, and is then floated using ethyl phenyl phosphonic acid or styrene phosphonic acid as the collector.

The dressing section for the upgrading of the table concentrates is similar to a mill–table circuit with the addition of a sulphide flotation circuit to remove the pyrite that has been recovered with the cassiterite.

The final gravity concentrate has a grade of about 60 to 62 per cent tin.

The tailings from the final 'line' of tables is further scavenged by a series of Humphreys spirals. Union Tin, however, return all the sand tailings to the regrind mill, so that the only material that leaves the concentrator is from the flotation section.

Bartles–Mozley Tables

The Bartles–Mozley table (Fig. 3) is a gravity concentrator of the 'flowing film' type. It consists of two 'sandwiches' containing 20 fibreglass decks, each of which is freely suspended at between 1 and 3 degrees to the horizontal. There is about 1 cm clearance between decks in the sandwich. The drive system, which imparts an orbital motion to the assembly, is located centrally between the two sandwiches, and comprises an out-of-balance weight attached by an arm to the drive shaft. Motive power is provided by a 0,37 kW variable-speed motor. The inclination of the decks is arranged to suit the particular characteristics of the mineral in question. The speed can be varied between about 200 and 300 r/min. The deck surfaces are smooth and are manufactured of 1,6 mm resin-bonded fibreglass, and are attached to the decks above and below by 1 cm thick plastic inserts.

The feed pulp is distributed evenly over the width of the table to all 40 decks in parallel. In operation, the table is essentially a batch process. The feed is run onto the deck for a predetermined period of time, at the end of which the whole table deck assembly is tilted to about 15 to 20 degrees to allow the remaining feed to drain. It is then tilted further to 45 degrees for the washing cycle. In tilting the table to 45 degrees, the discharge (now the table concentrates) is directed into a chute separate from the chute used for the table tailings. After washing, the deck assembly is returned to its original position, the washwater closed, and the slurry introduced for the next concentrating cycle. All the necessary valve operations and tilting of the decks are carried out automatically.

The concentrate from the Bartles–Mozley tables has a grade of about 3 to 4 per cent tin, and is further upgraded on a conventional shaking table to achieve a final grade of about 25 per cent tin. The capacity of the Bartles–Mozley table was found to be about 2 to 3 t/h.

The results of the Rooiberg operation are given in Table IV.

With the advances in flotation technology, it was found

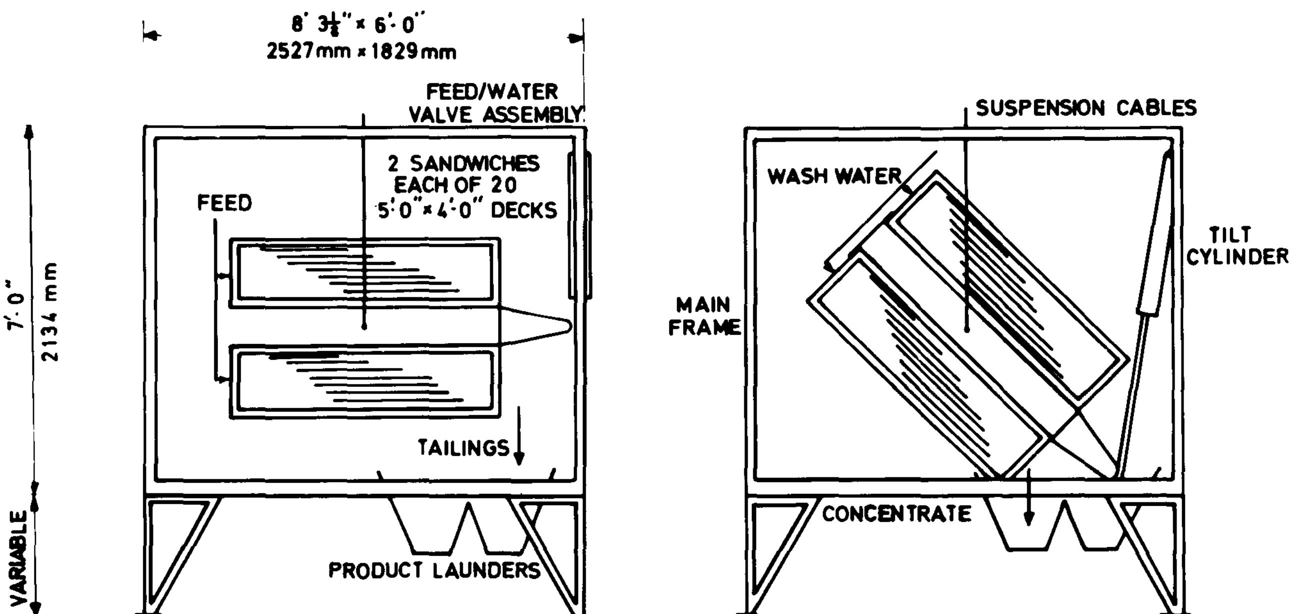

Fig. 3—A schematic diagram of the standard Bartles–Mozley concentrator

TABLE IV

METALLURGICAL BALANCE OF BARTLES–MOZLEY TABLE AT ROOIBERG

	Mass, %	Tin, %	Distn, %
Feed	100,00	0,522	100,00
Tailings	95,97	0,380	69,82
Concentrates	4,03	3,911	30,18
Dressing table			
Feed	100,00	3,911	100,00
Tailings	86,36	0,381	8,43
Concentrates	13,64	26,267	91,57
Over-all			
Feed	100,00	0,522	100,00
Tailings	99,45	0,380	72,37
Concentrates	0,55	26,267	27,63

that a flotation process for the fine fraction would be more efficient. Accordingly, a flotation plant was built in 1981 at the C Mine to replace the Bartles–Mozley tables. These tables have now been incorporated in the flotation circuit to scavenge the flotation tailings.

Other Concentration Devices

Two other types of concentration devices are used for cassiterite but have not been installed at Rooiberg. These are the Bartles Cross Belt Concentrator and the Reichert cone.

Bartles Cross Belt Concentrator

A further development arising from Mozley–Bartles tables is the Bartles Cross Belt Concentrator, the prototype of which was installed at the Geevor Mine in Cornwall in 1976 to treat the Bartles Frame concentrate. A final concentrate containing 20 per cent tin was achieved with a recovery of 70 per cent.

One test was carried out comparing the Bartles Cross Belt Concentrator with the Cornish round frame plus slime table running in series. The results, shown in Table V, indicate that the Bartles Cross Belt Concentrator achieved an enrichment ratio twice that of the two other units in series at a slightly higher recovery.

The sizing of the products from the Cross Belt operating at a high enrichment ratio indicates a 60 per cent recovery of material larger than 10 μm.

Reichert Cone

The Reichert Cone (Fig. 4) was developed in Australia, and is ideally suited as a preconcentrator, although it has been successfully used in secondary and tertiary conditions. It is a separator of the flowing-film type related to a pinched sluice, and has a high capacity. The feed material to the cone should be in the size range 1 mm to 53 μm.

BRGM Screens

In any gravity process, a proportion of the small heavy particles has a tendency to be misplaced and report with the large lighter fraction. The introduction of a static BRGM screen with a deck of 100 μm has been made to recover such misplaced material at Rooiberg. The heavy small particles fed to the screen gravitate to the bottom of the pulp stream and so are more easily recovered to the undersize. This undersize product is returned to the final line of tables. During a period in which the performance of this type of screen was monitored, the spiral tailings grade dropped from 0,19 to 0,15 per cent tin, which in this instance was equivalent to an additional 0,7 t of metallic tin recovered per month.

TABLE V

COMPARISON BETWEEN BARTLES CROSS BELT CONCENTRATOR AND ROUND FRAME WITH SLIMES TABLE

Fraction	Mass kg/h	Mass %	Sn assay, %	Sn distn, %	E.R.
Cross Belt Concentrator					
Concentrate	10,9	3,5	16,7	54,2	15,6
Tailings	300,5	96,5	0,51	45,8	
Head	311,4	100,0	1,07	100,0	
Round frame and slimes table					
Total slime concentrate	20,3	6,5	8,4	51,8	7,8
Tailings	290,7	93,5	0,54	48,2	
Head	311,0	100,0	1,06	100,0	

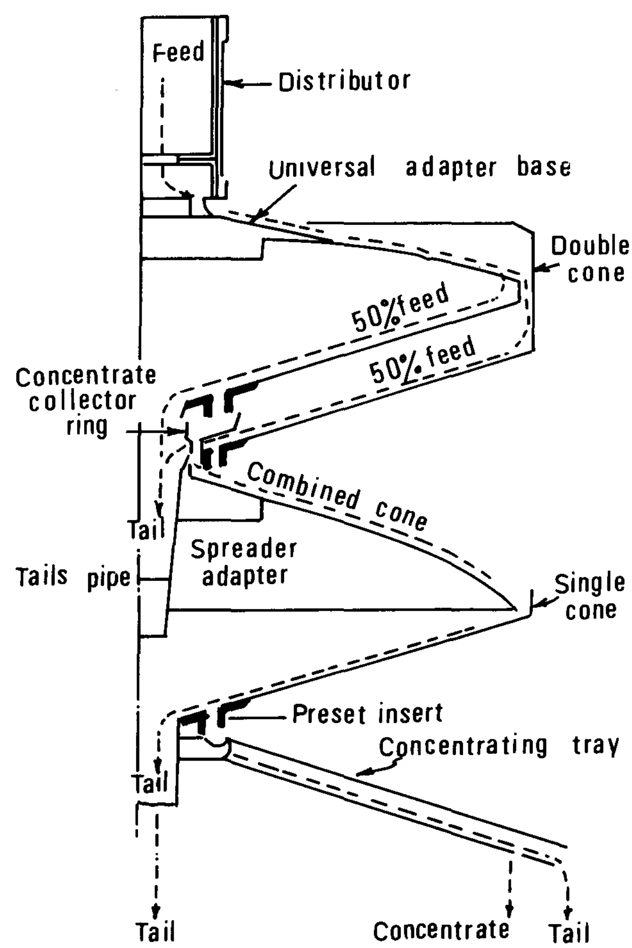

Fig. 4—A Reichert cone with a combination of double and single cones

Conclusions

The range of gravity-concentrating equipment used for the recovery of cassiterite is extensive, and most have, at one time or another, been used in a single concentrator. Except for recent work by Mozley, new devices and improvements to old devices are not common, but the scope for improvement in performance is considerable, especially in the fine size ranges. Beneficiating processes using gravity should therefore not be lightly dismissed in favour of more 'exotic', and certainly more-expensive, processes.

Bibliography

BURT, R.O. On stream testwork of the Bartles Cross/Belt Concentrator at Geevor Tin Mine — Cornwall. *Report* 130/5. Oct. 1976. Unpublished.

FALCON, L.M. Gravity recovery of fine tin using the Bartles-Mozley concentrator. *J. S. Afr. Inst. Min. Metall.*, vol. 76, spec. issue, Oct. 1975.

FALCON, L.M., and BULLED, D. Metallurgical advances in the tin extraction at Rooiberg Tin Limited. Unpublished report.

HASSEN, A.H.B. Treatment of alluvial tin ores at Gravel Pump mines in Malaysia. Simposia International del Estano, La Paz (Bolivia), 1977.

JONES, M.P. (Editor). *Mineral processing of tin ores*, vol 1. London, Institution of Mining and Metallurgy, 1967.

LEUBE, A., and STUMPFL, E.F. The Rooiberg and Leeuwpoort Tin mines, Transvaal, South Africa. *Econ. Geol.*, vol. 58. 1963. pp. 391-418.

MANTELL, C.I. *Tin — its mining, production, technology and applications*. London, Hafner Pub. Co., 1970. Chaps. 4 and 5.

MOSSNER, W. Tin — present and past. *Cert. Engr*, Feb. 1980. p. 550.

OTTLEY, D.J. Gravity concentrator design, and operation, developments and problems. *Min. Mag., Lond.*, 1978. pp. 33-43.

PRYOR, E.J. *Mineral processing*. London, Applied Science Pub., Chap. 14.

VAN DER SPUY, R.G.M. The treatment of tin ores in the Rooiberg concentrator. *J. S. Afr. Inst. Min. Metall.*, May 1961.

Carbon-in-pulp technology

The Perth Branch of the AusIMM is organizing a seminar on 'Carbon-in-pulp Technology for the Extraction of Gold' in Kalgoorlie, Western Australia, during the week 13th to 15th July, 1982.

The emphasis of the seminar will be on informal discussion of the up-to-the-minute state of the technology. Papers will be presented by representatives of operating companies, consultants, and tertiary institutions from Australia, South Africa, and the U.S.A. These papers will reflect the latest thinking in the theory, design, modelling, construction, and operation of carbon-in-pulp facilities. Tours of operating plants in the region will be arranged.

Individuals or companies interested in contributing a paper should write to Dudley J. Kingsnorth, Shell Company of Australia Limited, 200 St George's Terrace, Perth, 6000 Australia.

Statistics in resource development

The theme of the 6th Australian Statistical Conference will be 'Statistics in Resource Development'. The Conference is to be held in Melbourne from 23rd to 27th August, 1982.

International speakers will be Professor A. Journel (Stanford), Dr B. Ripley (Imperial College, London), Professor M. Armstrong (Fontainebleau, France). There will also be invited talks from Australian scientists. Contributed papers from intending participants are welcomed.

For further information of a technical nature, contact Dr Noel Cressie, The Flinders University of South Australia, Bedford Park. S.A. 5042, Australia.

For more information on the Conference contact Ian R. Gordon, Conference Secretary, Department of Statistics, University of Melbourne, Parkville. VIC. 3052, Australia.