# The application and design of wet-gravity circuits in the South African minerals industry

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**SYNOPSIS**

The application of Reichert spirals and cone concentrators within the South African mineral industry is discussed, and the procedures used in the acquisition of design data are outlined. Computing techniques developed by Mineral Deposits Limited for the processing of test data for use in the design of production circuits are described.

**SAMEVATTING**

Die gebruik van Reichert-spirale en -keëlkonsentreerders in die Suid-Afrikaanse mineraalbedryf word bespreek en die prosedures wat toegepas word om ontwerpdata in te win, word in hooftrekke uiteengesit. Berekeningstegnieke wat Mineral Deposits Limited vir die verwerking van toetsdata vir gebruik by die ontwerp van produksiekringe ontwikkel het, word beskryf.

## INTRODUCTION

The Research and Engineering Department of Mineral Deposits Limited manufactures the Reichert spiral and the Reichert cone, both of which have found wide application and acceptance throughout the mineral-processing industry, not only within South Africa but also worldwide. The fact that some fourteen chromium producers in South Africa rely on Reichert spirals to produce their fines products exemplifies the wide acceptance by industry of this type of wet-gravity concentrator.

Both the Reichert spiral and the Reichert cone were developed to meet the changing requirements of the mineral-sands industry in Australia. The history of this development and the application of these separators within that industry have been fully covered in the literature[1-3].

However, since the late 1960s, operators of mineral-processing plants outside the mineral-sands industry have applied the technology embodied in these devices to their own applications. As a result, these separators are being used, or have been used, for the recovery of chromite, manganese ore, tin, gold, uranothorianite, baddeleyite, diamonds, oxided copper–lead–zinc ore, garnets, and silica sand, as well as for mineral sands (rutile, zircon, ilmenite and monazite).

## REICHERT WET-GRAVITY CONCENTRATORS

### Spiral Concentrators

The range of Reichert spirals consists of the following models: Mark 2A, 2B, 3, and 6. The physical dimensions of these spirals are shown in Table I, while their individual trough profiles are shown in Fig. 1.

The Mark 2A and B trough profile is similar to that traditionally used for spirals produced by various manufacturers. These spirals differ from previous Reichert spirals in the design of the splitter and central column, and in the application of wash water. The difference between the metallurgical performance of these two spirals relates to the positioning of the concentrate splitter relative to the centreline of the spiral.

In the Mark 2A, the splitters are located some 26 mm closer to the spiral centreline than are the splitters of the Mark 2B. This results in a limitation on the portion of the solids in the spiral feed that can be taken as concentrate under normal operating conditions. This capability is made use of in some chromium applications, where the spiral feed consists predominantly of heavy minerals (with a relative density of more than 4), which tend to crowd the concentrate offtakes. Here the limiting effect

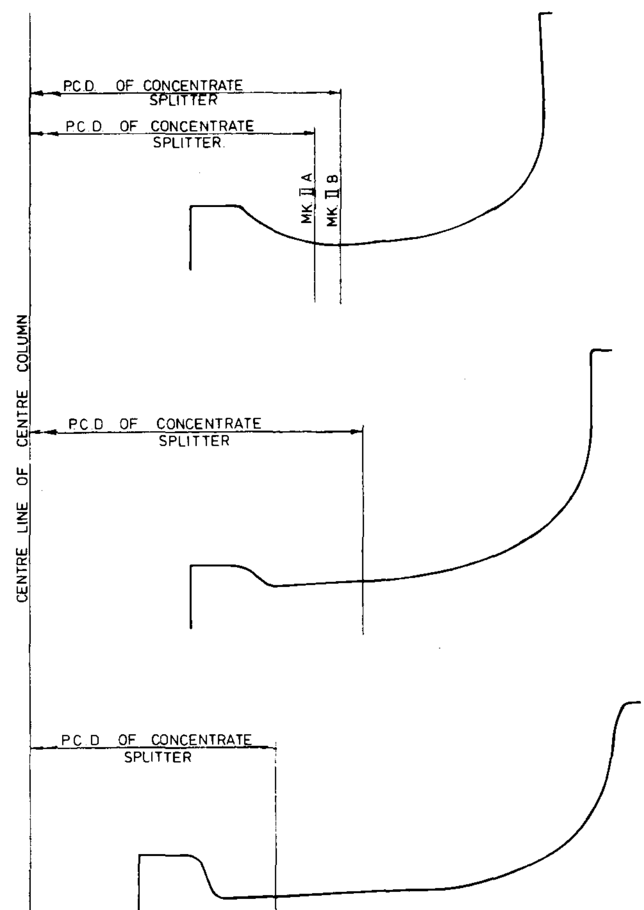


**Fig. 1.—Trough profiles of Reichert spirals (P.C.D.=pitch-circle diameter)**
**Top: Mark 2A and 2B. Middle: Mark 2A. Bottom: Mark 6.**

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TABLE I

DIMENSIONS OF REICHERT SPIRALS

| Model | Pitch of trough mm | P.C.D. of conct. splitters mm | Outside dia. of central column mm | Overall ht of assy mm | Outside dia. of trough mm |
|---|---|---|---|---|---|
| Mk 2A | 387 | 298 | 168,3 | 2370 | 590 |
| Mk 2B | 387 | 324 | 168,3 | 2370 | 590 |
| Mk 3A | 387 | 348 | 168,3 | 2370 | 640 |
| Mk 6 (5 turn) | 368 | 254 | 114,3 | 2054 | 610 |
| Mk 6 (7 turn) | 368 | 254 | 114,3 | 2835 | 610 |

P.C.D. —pitch-circle diameter.

of the Mark 2A splitter arrangements ensures sufficient selectivity to enable an acceptable grade of concentrate to be produced (Fig. 5). Another application of the Mark 2A spiral is where the heavy-minerals content of the spiral feed is very low (5 per cent by mass or less) and only a small proportion of the feed is required to be recovered in the concentrate. Such an application is the production of Silica Sand (Fig. 8).

The Mark 2B spiral, which has its splitters located further out into the slurry stream, tends to be more of an all-purpose spiral, and is employed in the majority of processing circuits for mineral sands, chromium, and tin.

The Mark 3 spiral has a centre column of the same diameter and the same pitch as the Mark 2 spirals, but has a flat bottom profile compared with the rather rounded profile of the Mark 2. The splitters are located further out in the mineral stream than for either of the Mark 2 spirals. However, the metallurgical performance and characteristics of this spiral depend on its redesigned profile. It tends to out-perform other spirals in roughing applications on ores having 5 to 40 per cent heavy minerals of more than 2,9 relative density, except perhaps on finely ground ores. The Mark 3 spiral has been shown to give a higher heavy-mineral recovery at the same concentrate grade in these applications. This spiral operates most efficiently over a higher range of feed pulp densities – 25 to 45 per cent solids (by mass) – than the Mark 2 spirals (15 to 35 per cent). The capacity of the Mark 3 spiral is also much higher than that of the Mark 2 for the same application: about 2,5 t/h per start, compared with about 1,5 t/h per start.

The Mark 6 spiral has a flat-bottomed profile similar to that of the Mark 3 spiral, but has a central column of smaller diameter, a reduced pitch (368 mm as against 387 mm), and a splitter location closer to the centreline of the spiral as a consequence of the smaller-diameter column. The Mark 6 has proved to be more selective than other spirals in terms of discriminating between minerals with a lower difference in relative density. It has also been found to perform better than other spirals on finely ground ore. For example, in recent testwork on chromium ore that had been ground to 80 per cent minus 74 $\mu$m, the Mark 6 spiral showed a superior metallurgical performance not only over other spirals but also over the Reichert cone. The Mark 6 spiral operates in the same density range as the Mark 3, i.e. 24 to 45 per cent solids by mass but, because of the nature of the applications, usually operates at a lower capacity (about 1,5 t/h per start).

## Cone Concentrators

The Reichert cone is a flowing-film type of concentrator consisting of a series of inverted conical concentration decks surmounted by conical distribution decks arranged in a vertical array and employing various combinations

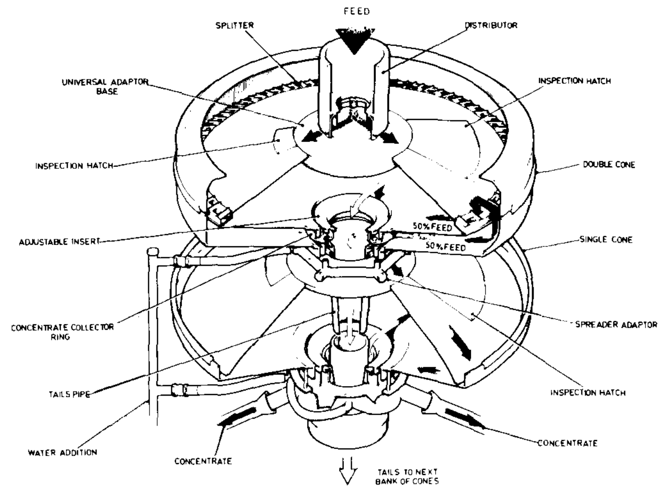


**Fig. 2—A DS (double cone, single cone) concentrator**

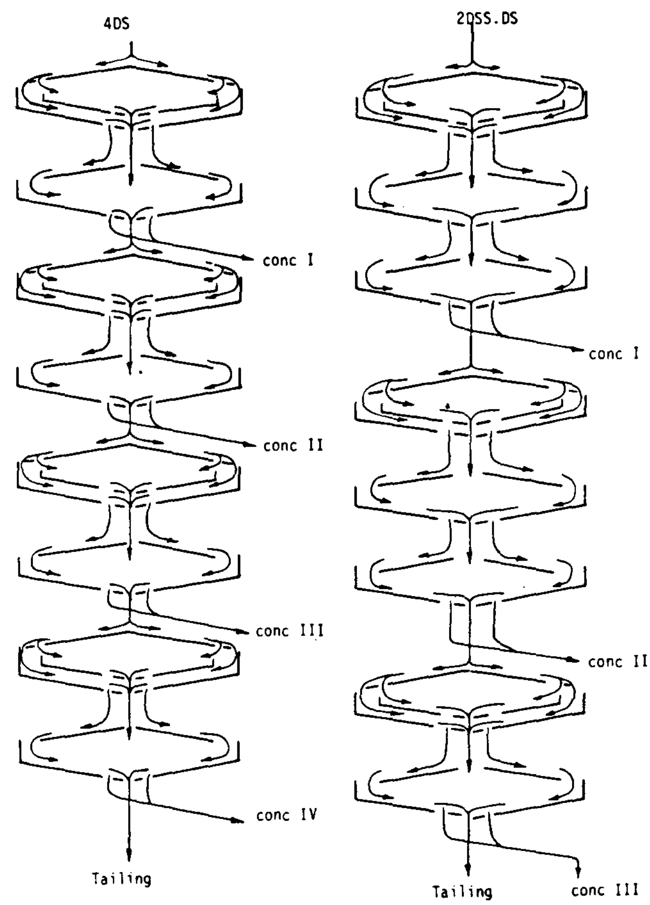


**Fig. 3—4DS and 2DSS.DS cone concentrator configurations**

of double- and single-deck elements. A DS (double cone, single cone) concentrator is shown in Fig. 2. The DS and DSS arrangements (or stages) form the basis of virtually all the configurations for cone concentrators. Configurations commonly used in production circuits, viz 4DS and 2DSS.DS, are shown in Fig. 3. The 4DS configuration consists of four DS stages assembled vertically with each S cone producing a concentrate and each of the three top DS stages producing a tailing, which is retreated on the subsequent stage. A final tailing is made from the fourth DS stage. Similarly, the 2DSS.DS configuration consists of two DSS stages surmounting a DS stage. Concentrates are produced from the second S of the DSS stages and the S of the DS stage.

All S cones are fitted with adjustable inserts in which, by means of a handle, the inner section of the insert can be moved vertically in relation to the outer section. This enables the concentrate take to be varied while the cone is 'on stream'. This provision can be readily automated if necessary, so that the circuit can achieve the flexibility needed to cater for variations in grade and throughput.

All S cones also have facilities for the addition of dilution water to control independently the pulp density of the feed on individual single cones.

## APPLICATIONS

### Feed Preparation

The operational characteristics of the Reichert cone have been investigated by the Department of Mineral Processing, University of Lulea[4]. The cone concentrator was found to be most selective in the particle-size range 40 to 500 $\mu$m while normally operating at a pulp density of between 30 and 35 per cent solids by volume. The usual capacity is between 50 and 90 t/h of solids. The ranges of these operating parameters are often extended in one or more directions in particular applications.

However, it is obvious that the cone requires a prepared feed for optimum operational results. Factors requiring control are the size range of the particles, the pulp density of the feed, and the feed rate.

The size range of the particles is controlled by coarse screening to remove tramp material and particles coarser than 3 mm and preferably 1 mm. The lower size is controlled by preliminary desliming before the cones. This is achieved mostly by cyclones, their operating parameters often varying from one application to another depending on the size range and relative density of the valuable heavy minerals. Cyclone separation $d_{50}$ from 50 to 20 $\mu$m has been employed. As a general rule, it is desirable for the minus 30 $\mu$m fraction of the solids in the cone feed to be less than 8 per cent by mass.

The pulp density of the feed to a cone circuit requires to be maintained within a fairly narrow range. This is normally achieved by a simple automatic density-control loop incorporating a nuclear density gauge and a controller varying the water addition, pump speed, or slurry bypass. The optimum range of pulp density for a particular application is determined experimentally either in initial tests or under actual operating conditions.

The cone is relatively more tolerant of variation in feed rate than in feed pulp density. However, there is an optimum range of feed rates, which can be determined from testwork. Large and frequent changes in feed rate are, of course, detrimental to optimum circuit performance.

Spiral circuits require similar feed preparation to that outlined for cone circuits. However, spirals can generally operate effectively over a much wider range of feed densities than can cones. This often eliminates the need for automatic density control. Similarly, spirals can tolerate a fairly wide range of solids feed rates (75 to 125 per cent of design rate) in most applications. Some of the new spirals now available have a 'peaky' performance and do not exhibit the flexibility attributed to previous spirals. This characteristic should be investigated during initial tests.

The operating size range of the Reichert Mark 2 and 3 spirals is coarser than that of the cone. The optimum size range has a lower limit of around 70 $\mu$m, while the upper limit remains at around 500 $\mu$m. The Mark 6 spiral operates over a similar size range to the cone. As with cone circuits, prescreening of the feed is essential to remove coarse and tramp material that could cause blockages and precipitate sanding up of the troughs. Slime removal is also necessary in most applications but, because the feed density for the spiral can be lower than that for the cone, the amount of slimes that can be tolerated, expressed as a percentage of the total solids in the spiral feed, may be greater than that which can be tolerated by the cone.

Both cones and spirals require a relatively clean water supply for dilution and wash water. It is essential that this water should be free of particles such as wood chips, leaves, coarse solids, etc., which would cause blockages in the water manifolds of the concentrators. It is therefore usually necessary to screen the circuit water supply at about 1 mm to prevent operating problems from this source.

### Spiral Circuits

*Chromium Ore*

Virtually all of the South African producers of chromium fines employ Reichert spirals in their operations, although the circuits vary considerably.

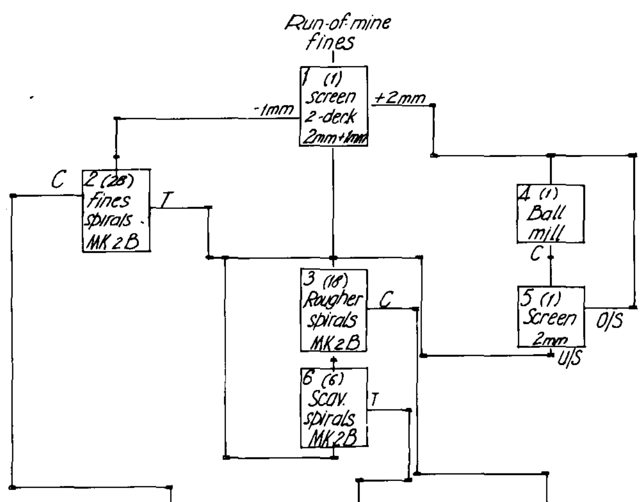


Fig. 4—Circuit at Gencor's Montrose and Groothoek Mines

The circuit employed by Gencor at both its Montrose and Groothoek Mines is shown in Fig. 4. In this circuit, minus 1 mm run-of-mine fines are treated in a separate spiral circuit to produce a high-grade concentrate. The plus 2 mm material is milled to minus 2 mm and is then combined with the natural minus 2 plus 1 mm fraction to a second spiral circuit to produce a low-grade concentrate. Both circuits report $Cr_2O_3$ recoveries in excess of 92 per cent. Mark 2B spirals are used throughout.

The circuit employed by Rand Mines at their Winterveld Mine is shown in Fig. 5. The spiral circuit is operated as a split circuit. This circuit has been in operation for some two to three years and shows a different approach in that the whole range of fines is treated in one circuit. The plus 1,5 mm natural fines are ground to minus 1,5 mm and join the natural minus 1,5 mm fines as feed to the spiral circuit. Originally the screens produced a spiral feed with a top size of 0,833 mm. This resulted in a product with less than 1 per cent silica for a $Cr_2O_3$ recovery of 75 per cent. The currently installed screens produce a top size of 1,5 mm to the spiral circuit, which in turn produces a product assaying 1,5 per cent silica with a $Cr_2O_3$ recovery of 84 per cent. This circuit uses Mark 2A spirals as roughers to produce a final concentrate, and Mark 2B's in the secondary and tertiary stages that perform scavenging functions. It has been found that the optimum pulp density of the feed to each spiral stage is 25 per cent solids by mass, and dewatering cyclones are employed ahead of the secondary and tertiary stages to obtain this required pulp density.

The circuit employed by the Dunn Plant of Rand Mines is shown in Fig. 6. In this circuit, spirals are used in conjunction with diamond pans to produce a range of products. The minus 2 mm run-of-mine fines are treated on Mark 2B spirals, which make a concentrate assaying less than 1 per cent silica. The spiral tailings are retreated on diamond pans to produce a final tailing and a refractory-grade concentrate.

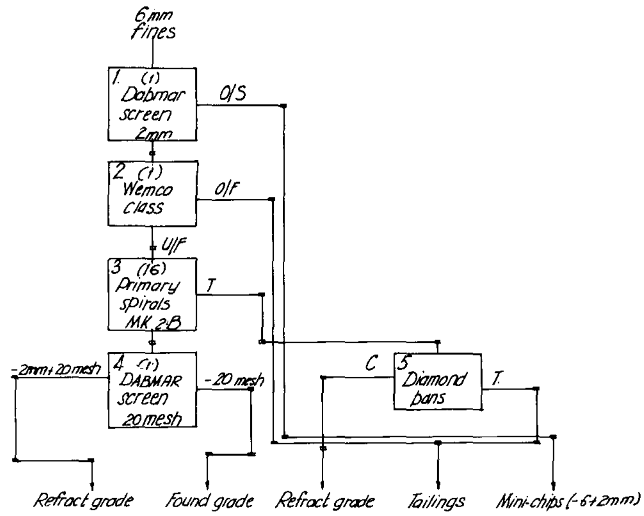


**Fig. 6—Circuit at Rand Mines' Dunn plant**

Mining Corporation's Dilokong Mine employs a two-stage spiral circuit using Mark 2B spirals to produce a chemical-grade product assaying less than 0,9 per cent silica with a maximum particle size of 0,8 mm. The circuit is shown in Fig. 7. The Mark 2B spirals were chosen on the basis of the results obtained from tests on a closed circuit with three possible size fractions. These results, which are given in Table II, showed that

(a) while the 2A and 2B spirals produced a similar grade of concentrate, the $Cr_2O_3$ recoveries were higher from the 2B machine,
(b) concentrate grades of less than 1 per cent silica could be confidently expected, and
(c) grinding the ore to minus 1 mm resulted in a higher recovery of $Cr_2O_3$.

*Tin*

UIS Tin Mine in South West Africa employs a two-stage spiral circuit supplemented by James tables to treat the cleaner concentrate from the two spiral stages.

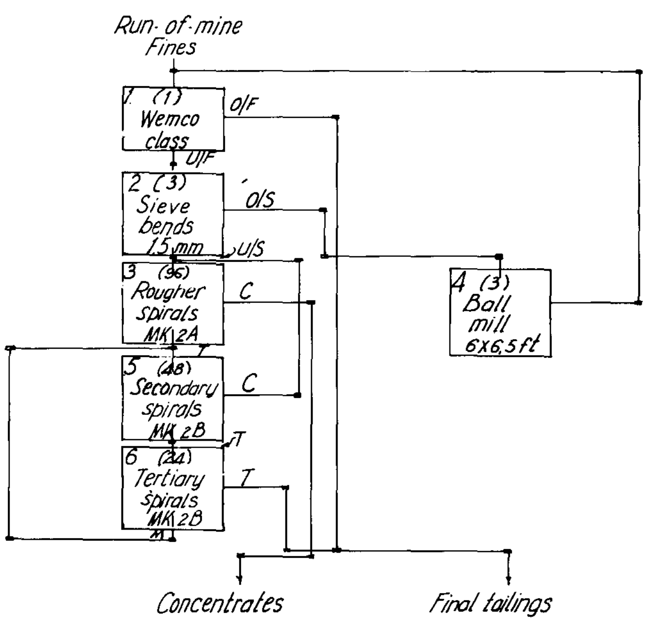


**Fig. 5—Circuit at Rand Mines' Winterveld plant**

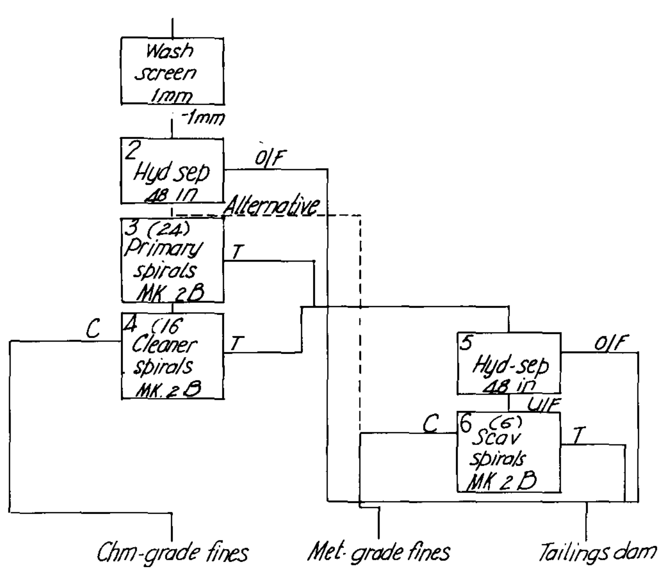


**Fig. 7—Circuit at Mining Corporation's Dilokong Mine**

The feed to the spiral circuit is ground to minus 0,5 mm and is deslimed by cyclones ahead of the spiral circuit. The primary spiral stage consists of twenty-four Reichert Mark 2B spirals, eight Spargo Cyclo-Spirals and eight Xatal spirals. The cleaner spiral stage retreating the primary spiral concentrate contains twenty-four Reichert Mark 2B spirals. Primary and secondary jigging circuits are installed on the plus 0,5 mm streams.

Zaaiplaats Tin Mines reprocesses[5] an accumulation of old tailings amounting to some 3 Mt at the rate of 20 kt/m. The reclaimed tailings are screened to remove tramp material and coarse tailings. The fine sand is transferred to the plant, where the fines are removed in a rake classifier and the minus 180 $\mu m$ sand is pumped to a cyclone whose underflow feeds four Reichert Mark 2B spirals. The spiral concentrates are retreated on tables.

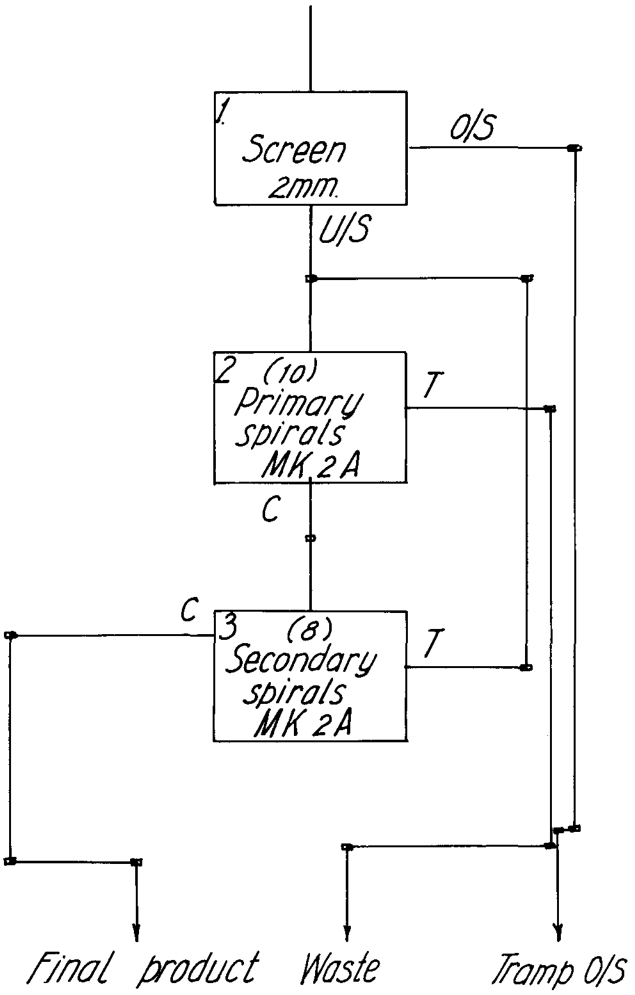


Fig. 8—Circuit at Graded Sands, Kwambonombi (Natal)

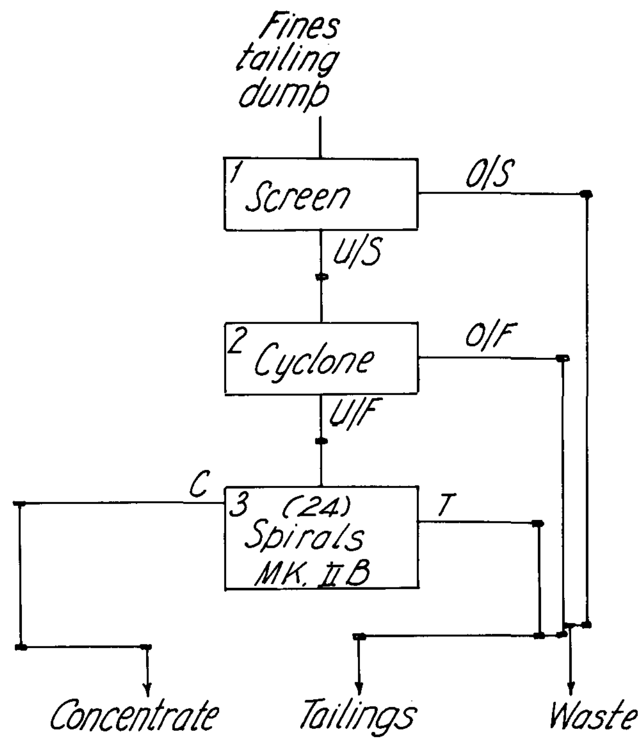


Fig. 9—Circuit at Gopani Manganese

TABLE II
DILOKONG SPIRAL TEST RESULTS

| | | | Spiral concentrate | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Assay, % | | | Distn, % | | |
| Test | Mesh, mm | Spiral | $Cr_2O_3$ | Fe | $SiO_2$ | $Cr_2O_3$ | Fe | $SiO_2$ |
| T1 | −1 | 2A | 49,60 | 20,33 | 0,60 | 81,1 | 79,9 | 12,9 |
| | | 2B | 46,40 | 20,11 | 0,70 | 92,6 | 91,7 | 23,1 |
| T2 | −1 | 2A | 46,40 | 19,94 | 0,78 | 81,1 | 79,9 | 21,1 |
| | | 2B | 46,66 | 20,16 | 0,56 | 82,9 | 81,0 | 12,1 |
| T3 | −1 | 2A | 47,16 | 20,05 | 0,78 | 83,5 | 82,1 | 21,3 |
| | | 2B | 46,90 | 19,99 | 0,78 | 90,0 | 88,7 | 23,8 |
| T4 | −1 | 2A | 47,12 | 20,66 | 0,58 | 82,9 | 82,6 | 13,3 |
| | | 2B | 47,01 | 19,99 | 0,68 | 88,0 | 86,5 | 18,3 |
| T5 | −2 | 2A | 47,01 | 20,44 | 0,76 | 79,1 | 78,4 | 20,6 |
| | | 2B | 46,44 | 20,38 | 0,62 | 84,9 | 83,8 | 16,4 |
| T6 | −4 | 2A | 47,08 | 20,22 | 0,60 | 72,2 | 70,7 | 11,2 |
| | | 2B | 46,70 | 20,32 | 0,70 | 82,0 | 80,9 | 18,7 |

The tests were run at the following percentage solids:

| | | | |
|---|---|---|---|
| Test | T1 | 12,5% | −1mm material |
| | T2 | 9,0% | |
| | T3 | 15,0% | |
| | T4 | 21,4% | |
| | T5 | 13,1% | −2mm material |
| | T6 | 11,3% | −4mm material |

The cyclone overflow, essentially minus 75 $\mu$m, is further classified by a hydroclassifier before tabling.

*Silica Sands*

Graded Sands at Kwambonombi, Natal, produce a silica sand product from a two-stage spiral circuit (Fig. 8). Screened feed is passed over a two-stage circuit in which the primary spiral tailings are treated on the secondary spirals. Mark 2A spirals are used in both stages because of the small amount of heavy minerals present and the small concentrate take. The feed materials assay 2,0 per cent iron, while the primary spiral tailings run 0,26 per cent iron and the final product, 0,06 per cent iron.

Gopani Manganese retreat a slimes dam through a single-stage spiral circuit (Fig. 9). The grade of the feed from the dam is about 20 per cent $MnO_2$, while the concentrate assays around 40 per cent $MnO_2$. This represents a recovery of 50 per cent of the $MnO_2$ into a product comprising 25 per cent of the mass of the feed.

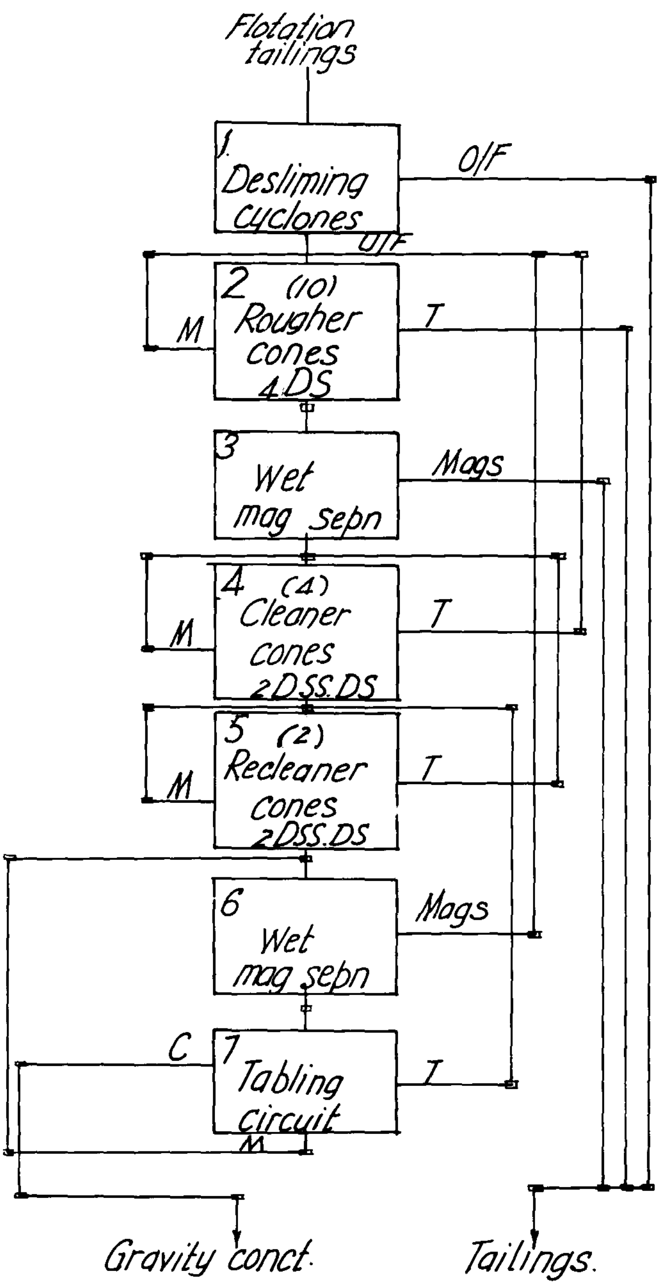


Fig. 10—Circuit at Foskor's heavy-minerals plant

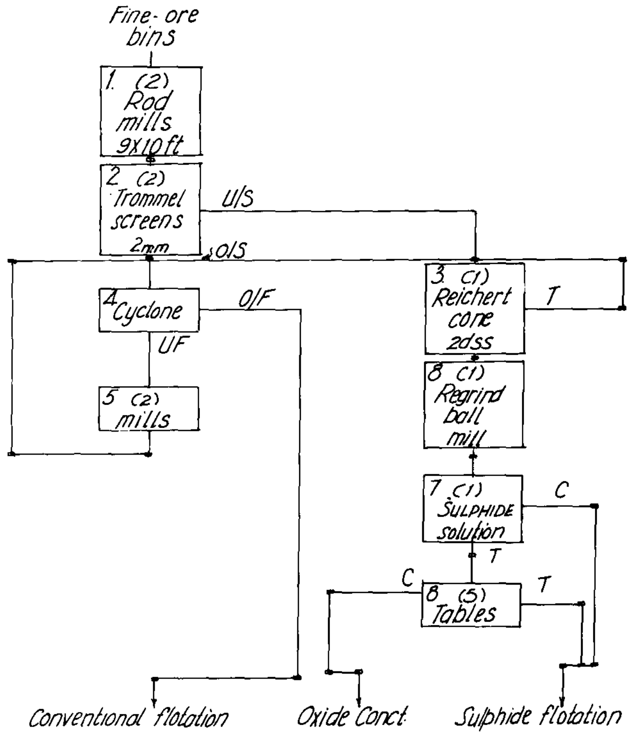


Fig. 11—Circuit at Tsumeb Corporation

## Cone Circuits

*Mineral Sands*

Richards Bay Minerals operate a large separation plant producing rutile, zircon, and ilmenite from dunal deposits. The primary wet-gravity separation is achieved in a floating concentrator plant employing a multi-stage Reichert-cone circuit supplemented by spirals. A high-grade heavy-mineral concentrate is stockpiled in dedicated areas before being trucked to a mineral-separation plant, while the silica sand is redeposited at the rear of the dredge pond[6].

*Tailings Scavenging*

Palabora Mining Company operates a heavy-minerals plant to recover very small quantities of uranothorianite and baddeleyite ($ZrO_2$) from the tailings from its copper-flotation circuit[7]. This is currently the largest Reichert-cone installation in existence.

Concentrates from the five-stage cone circuit are further upgraded in a tabling circuit to produce a uranorthorianite-rich concentrate and a baddeleyite-rich concentrate. A high operating standard is maintained in the plant, with regular measurements of tonnages and densities at all possible points within the circuit. Frequent inspections of all cone splitters, distributors, etc. ensure optimum cone-operating conditions. As a result, satisfactory mineral recoveries are achieved even down to very fine particle sizes (20 $\mu$m).

Typically, the feed to the rougher cones assays 0,0035 per cent $U_3O_8$ and 0,40 per cent $ZrO_2$. Quaternary-cone concentrates (table-circuit feed) assay 0,082 per cent

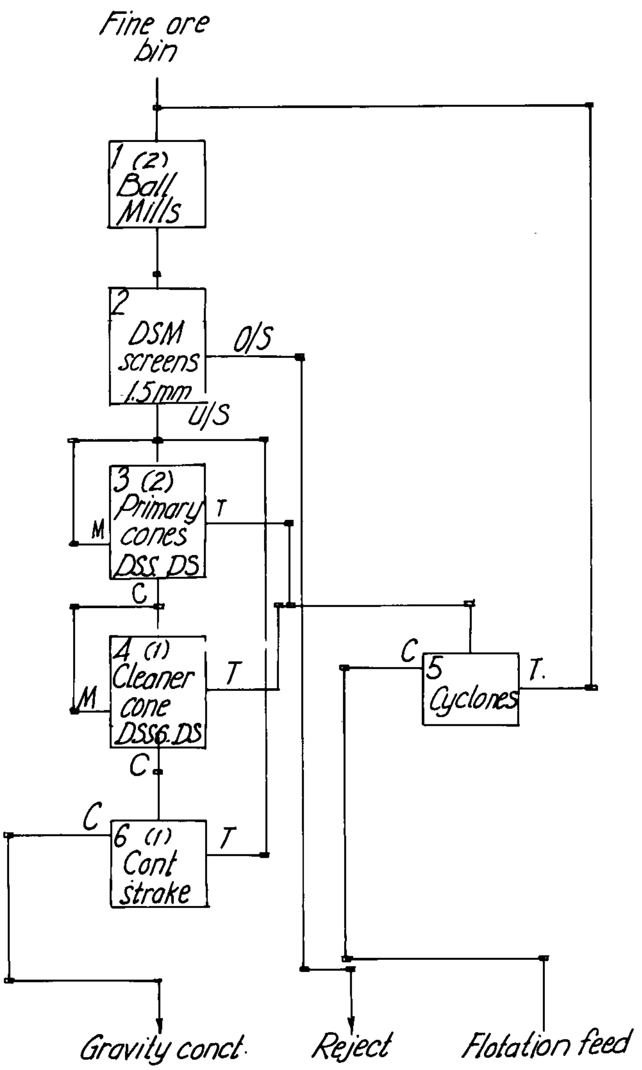


**Fig. 12—Circuit at Western Mining Corporation's Kambalda plant**

$U_3O_8$ and 17,5 per cent $ZrO_2$. The recovery of $U_3O_8$ and $ZrO_2$ into quaternary-cone concentrates under these conditions is approximately 70 per cent.

The Phosphate Development Corporation (Foskor) has also installed a wet-gravity circuit to recover baddeleyite from the tailings of its phosphate circuit. A three-stage cone circuit is supplemented by a tabling circuit to produce a wet-gravity concentrate that is subsequently upgraded by dry-magnetic separation to produce a final product. The flowsheet of the plant is shown in Fig. 10.

*Flotation Circuit*

Tsumeb Corporation treats mixed sulphide and oxide ores primarily by flotation. However, a type 2DSS Reichert-cone concentrator has been installed in the grinding circuit to reduce the head value of oxide minerals to the flotation circuit. The quantity of flotation reagents used in flotation is thereby reduced, resulting in a significant cost saving. A condensed flowsheet is shown in Fig. 11.

*Grinding Circuits*

The potential for Reichert-cone concentrators in closed circuit with grinding mills has not been realized in the South African mineral-processing industry as it has in Australia, particularly at Renison Limited, Ardlethan Tin Limited[8], Peko Mines (Warrego Concentrator)[9, 10] and Western Mining Corporation, Kambalda (Fig. 12). The first two installations recover tin, while the last two circuits recover gold.

The cone has the capability of removing liberated heavy minerals from ground ore, and this ability can be of significant metallurgical benefit in grinding circuits where the valuable heavy minerals present are more readily degraded than the gangue, e.g. cassiterite, wolframite, scheelite, uraninite, and pyrite. The classification effect of the cone is probably as good as some cyclone installations in closed circuit with grinding mills. Certainly, a combined cone concentrator–classifier installation would provide a sharper size separation than many cyclone installations while at the same time removing fine liberated valuable minerals from the circuit before they are further degraded. The circuit water balance would not be upset.

A Reichert-cone circuit was installed at Anglo American's President Steyn mine in place of a conventional gravity circuit, i.e. after milling and classification. However, owing to various operational problems, this circuit is no longer in service.

## DESIGN OF WET GRAVITY CIRCUITS

### Spiral Circuits

Most Reichert spiral circuits in South Africa have been based on closed-circuit tests, but the test programme can be designed to accommodate multi-stage circuits if required. The testwork can be undertaken under the supervision of Mineral Deposits Limited at Applied Mineral Research Laboratories' facilities. However, test spirals have been installed in existing plants for tests on either open or closed circuits.

Provided reasonable precautions are taken to ensure that representative samples are tested and that minimum degradation of the sample occurs, the test results can be expected to be duplicated in the production circuit, as has been achieved in relation to the Dilokong chromium circuit. The small unit capacity of individual spirals means that production-scale models (1 to 2,5 t/h of solids) are easily and cheaply tested in relatively small installations. In a well-designed spiral test rig, only 10 kg of sample may be required.

Provided a sufficient number of tests covering the expected range of operating conditions are undertaken, computer techniques developed by Mineral Deposits Limited can be used to optimize the circuit and its operating parameters.

### Cone Circuits

While the testing of production-scale spirals is accomplished easily and cheaply, the testing of production-scale Reichert cones, either in closed or open circuit, can be difficult and costly. The high capacity of the cone (60 to 90 t/h) demands fairly large samples for closed-circuit tests and an expensive installation for open-circuit testing. In recognizing this fact, Mineral Deposits Limited has adopted two approaches. The first uses mathematical modelling techniques on a limited number of results from a specially designed test programme undertaken on a DSVSV test rig. The second approach involves testwork on a Mark 6 tray assembly, which simulates the separation characteristics of the production Reichert cone.

A tray assembly has the capacity to handle 3 to 5 t/h of solids, and thus reduces both the cost of the test facility and the size of sample required to give data that can be used directly in the design of a production-cone circuit and the prediction of its performance.

## Simulation Models

Simulation models should ideally be based on test data that describe the response of the feed material at all stages of the treatment envisaged in a production plant. This ideal is difficult to achieve in practice because each application of a separation technique alters the composition of the feed to succeeding stages in terms of the distribution of sizes, shapes, relative densities, and compositions of particles present. The problem becomes even more severe where multiple separations occur within one machine, e.g. a cone concentrator may make up to nine separations in both series and parallel flow before releasing the products.

The design of a suitable test facility is an important element in any successful approach to testwork, particularly where simulation techniques are involved. The object is to generate an adequate range of test data for a unit separator so that a performance model can be constructed for the unit. In the case of cone concentrators, for example, the unit is a single cone and the first test facility consisted of precisely that. However, it proved impossible to devise test programmes or feed-blending techniques that would accurately duplicate the various feed compositions reaching individual cones within a multistage cone unit. A multistage test unit is thus clearly desirable and can be achieved without undue difficulty where the flows in the machines are readily accessible for sampling, as with spiral concentrators or tray separators.

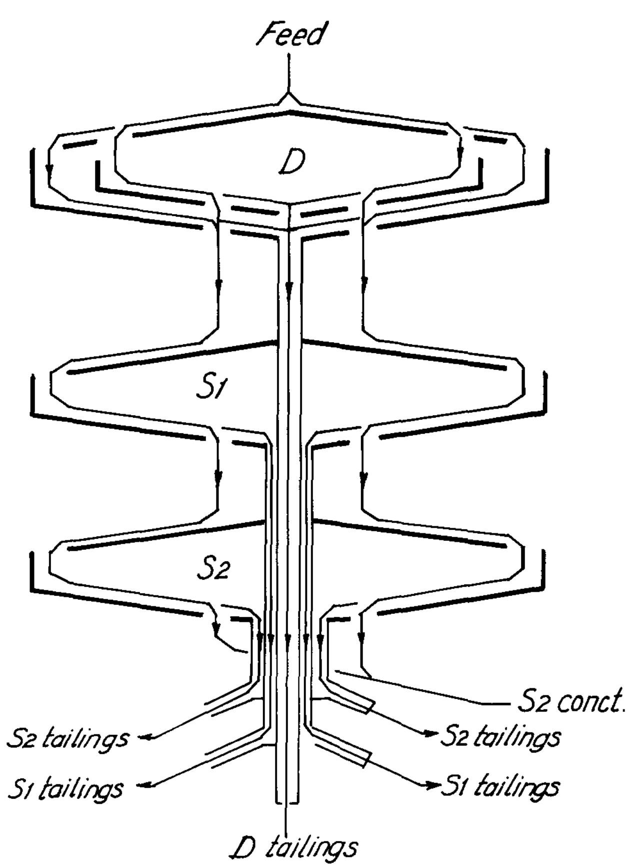

**Fig. 13—A DSVSV cone test rig**

Cone concentrators constituted a special case because of the inaccessibility of the internal tailing flows and the fact that these flows are combined progressively after each separation. The solution was to use a DSVSV unit equipped with a special concentric pipe sampler that isolates the individual tailing flows so that the performance of each cone in the test unit can be calculated by combining the sample results in sequence (Fig. 13).

The most important requirement of any test programme is basically so simple that it can be overlooked: it is to ensure than all the variables capable of exerting a decisive effect on the separation are investigated over the anticipated operating ranges. If the latter are particularly narrow, some tests outside the limits should be included to cover abnormal plant conditions.

The test sequence currently employed with the DSVSV cone unit is shown in Table III. A full factorial sequence for the S2 cone was avoided since this would have required 54 tests instead of 18. The variation in feed tonnage was reduced from three levels to two after a number of test programmes had been executed because unavoidable variations in the test conditions provided a sufficient range of values. This reduced the original sequence of 27 tests to the present level of 18.

A medium to large plant simulation requires between one and four test series of the type shown in Table III, depending on the upgrading and recovery targets set for

TABLE III
DSVSV CONE TEST SEQUENCE

| Series | Test no. | Feed rate t/h | Insert settings | | |
|---|---|---|---|---|---|
| | | | D | S1 | S2 |
| 1. Double Cone @ 1 | 1 | 70 | 1 | 1 | 1 |
| | 2 | | 1 | 5 | 1 |
| | 3 | | 1 | 9 | 1 |
| | 4 | 90 | 1 | 1 | 1 |
| | 5 | | 1 | 5 | 1 |
| | 6 | | 1 | 9 | 1 |
| 2. Double Cone @ 5 | 7 | 70 | 5 | 1 | 5 |
| | 8 | | 5 | 5 | 5 |
| | 9 | | 5 | 9 | 5 |
| | 10 | 90 | 5 | 1 | 5 |
| | 11 | | 5 | 5 | 5 |
| | 12 | | 5 | 9 | 5 |
| 3. Double Cone @ 9 | 13 | 70 | 9 | 1 | 9 |
| | 14 | | 9 | 5 | 9 |
| | 15 | | 9 | 9 | 9 |
| | 16 | 90 | 9 | 1 | 9 |
| | 17 | | 9 | 5 | 9 |
| | 18 | | 9 | 9 | 9 |

the plant. One series is usually performed on the feed material as received, and subsequent series are conducted on material either depleted in values by bleeding-out from the test rig or augmented by the addition of extra values.

A total or 'factorial' test design would require that each variable is tested at every possible combination of settings employed for the other variables, so that any side-effects or 'interactions' caused by unusual combinations of settings are not overlooked. In practice, the number of tests involved becomes very large as the numbers of settings (levels) and variables are increased.

One project on which this simulation technique was used was the investigation of the amenability of Reichert cones to preconcentrate tailings recovered from the Crown Mines dump prior to milling and cyanidation for the recovery of the contained gold. The solids, water, gold, and sulphur values were measured for all flows in the DSVSV test cone, and a graph of the solids flow in the concentrates against solids flow in the head feed was drawn to show the relationships (Fig. 14).

A regression model of an individual cone element was derived that gave the following RSQ values: 0,94 for solids flow, 0,89 for water flow, and 0,93 for gold flow. While not as good as normal mineral-sands models, this goodness of fit was considered acceptable in view of the nature of the material.

The goodness of fit for the model of solids flow in the

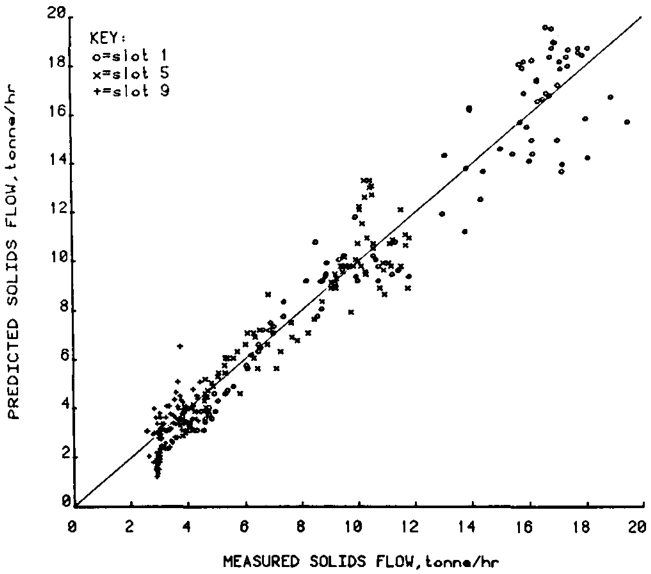


**Fig. 14—Solids flow in concentrate versus solids flow in feed**

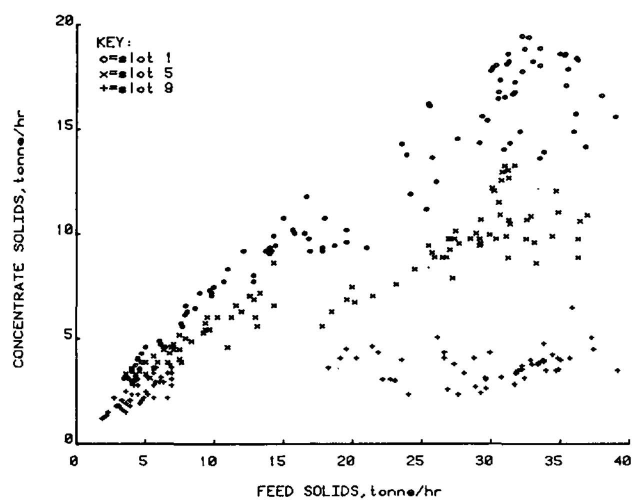


**Fig. 15—Goodness of fit of the solids-flow model**

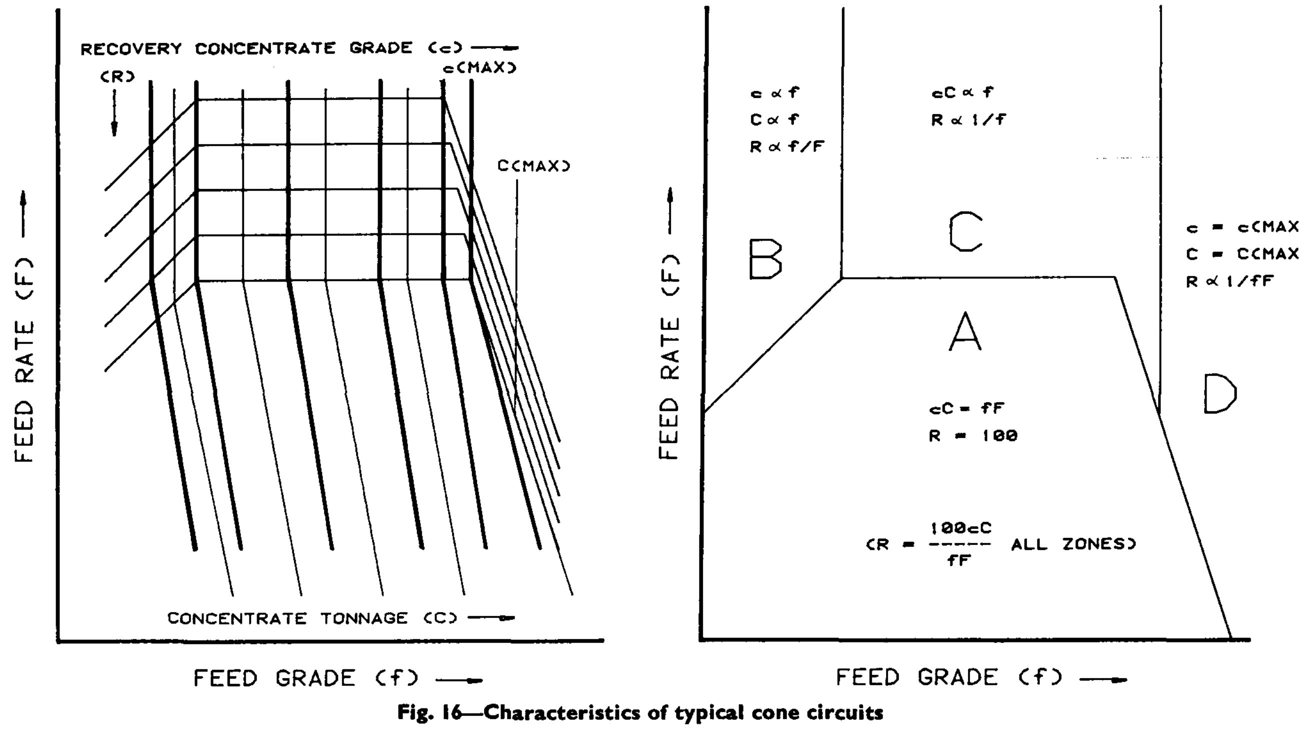


**Fig. 16—Characteristics of typical cone circuits**
**Left: Characteristics of an ideal circuit** **Right: Zones of behaviour**

concentrates is illustrated in Fig. 15, in which the predicted flows were plotted against the measured flows in the concentrates for each of the test results shown in Fig. 14.

The next step in a simulation exercise is the evaluation of possible cone configurations for the various stages in the production circuit, e.g. roughing, scavenging, cleaning. This is done by the use of a simple optimizing programme that provides a stepwise hill-climbing routine operating on the feed and cone variable in either an upstream or downstream sequence.

Finally, any number of case studies can be conducted for specified circuit-operating parameters to determine the circuit characteristics in relation to these parameters. The form of circuit characteristics found from a number of independent studies is typified by Fig. 16. It constitutes response surfaces for both grade and recovery in final concentrates, plotted against feed grade and feed rate on the $x$ and $y$ axes respectively.

The behaviour typified by this diagram is divided into four distinct zones.

*Zone A.* Both concentrate grade (light lines) and concentrate tonnage (heavy lines) increased with feed grade and tonnage, but at such a rate that the recovery was always 100 per cent. That was not a practical area in which to operate since the circuit was operating well below design capacity.

*Zone B.* Both concentrate grade and concentrate tonnage varied with feed grade, but were independent of feed rate, so, if the feed grade and rate were increased in proportion, the recovery would remain constant.

*Zone C.* Concentrate grade was determined by feed grade and recovery by feed rate. That was the zone in which the circuit was designed to operate and target concentrate grades should always be obtained. Recovery could then be adjusted by controlling the feed rate.

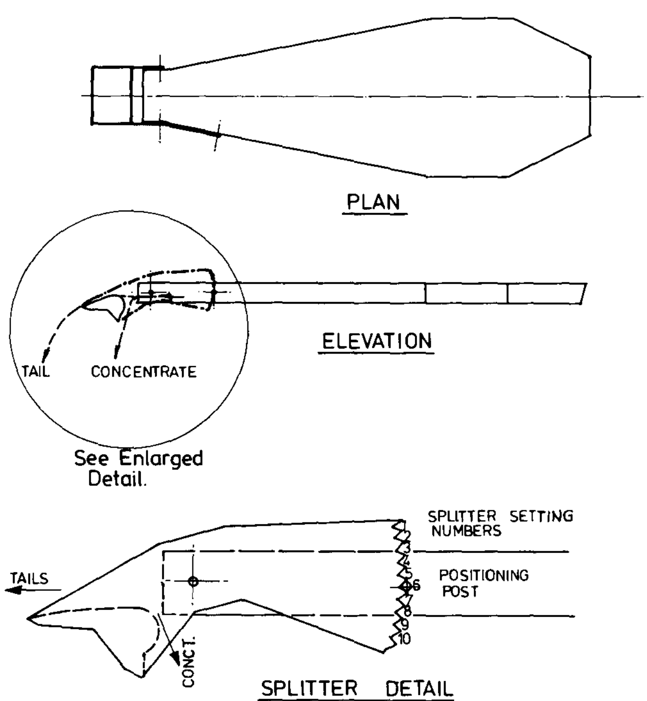


**Fig. 17—Details of the Mark 6 tray**

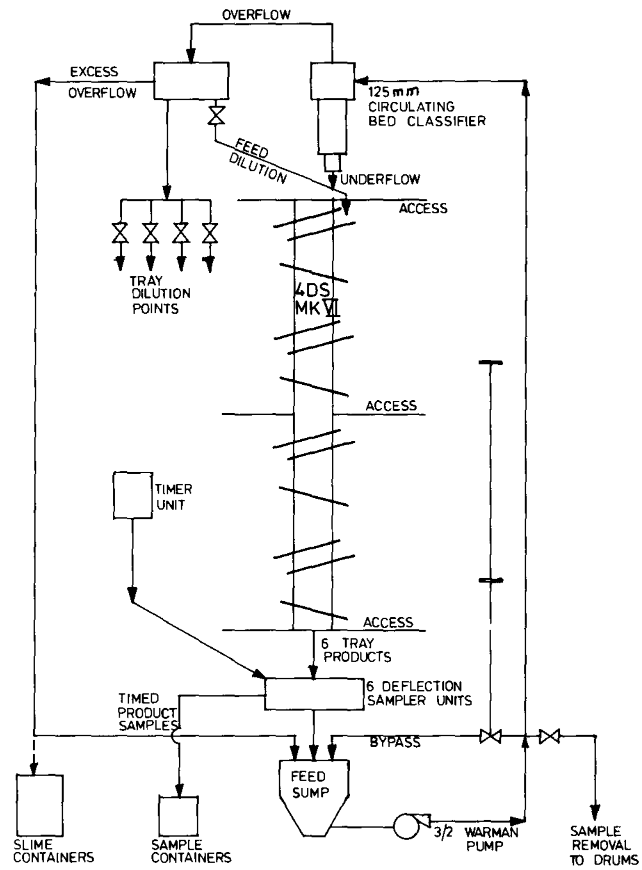


**Fig. 18—A typical closed-circuit test facility using the Mark 6 tray assembly**

*Zone D.* Near the border of Zones C and D, the concentrate grade reached a maximum (95 to 100 per cent), and at the boundary the circuit reached its maximum possible output of concentrate. Subsequent increases in feed grade or tonnage produced proportional losses in recovery. Control adjustments in that zone were difficult since the feed grade had exceeded the design limits and the recovery was unstable. As extreme reductions in feed rate could stabilize performance in Zone A, that was the only option other than modification of the circuit.

The performance described by the characteristic could thus be related to operating conditions in a straightforward manner. A possible exception to that statement was the decline in recovery with feed grade in Zone B. That might be ascribed to two possible causes: first, the lower-grade tests were conducted on depleted feed material and the remaining values might well exhibit lower probabilities of recovery; and, secondly, at low contents there might be a change in the separation mechanism of the pinched sluices. The dense, slowly moving layer of particles present at the bottom of the flow must disappear at low feed grades, and it was possible that flow velocities in the bed inhibited the separation of isolated heavy grains into the concentrate. Plots of this kind have been found to be very useful in the development of operating and control strategies for proposed plants.

The results contain a considerable accumulation of potential error from the numerous calculations involved, plus further errors of unknown magnitude because of inadequacies in the design or execution of the test programme and the use of a model based on closed-circuit tests to predict performance in open circuit. The latter error is known from previous experience to be small for the equipment under consideration, and one other common source of error, the scale effect, is totally absent because of the use of full-scale equipment in all the tests. Thus, although the response surfaces must be interpreted with due caution when used for the prediction of metallurgical production, they are considered to provide a reliable guide to the type of behaviour that will be exhibited by a particular circuit. A detailed study of a complex cone circuit using this techinque is discussed in the literature[11].

### Mark 6 Tray System

The Mark 6 tray (Fig. 17) is a pinched-sluice device that can be considered to simulate the separation characteristics of a single cone deck but at one twentieth of the feed rate. Individual tray elements are arranged in a tray assembly to duplicate the internal-flow configuration of production-model cone concentrators. As standard, the 4DS (or 2 × 2DS) configuration is employed. Test results obtained from this device can therefore be used directly in the design and prediction of the performance of a production-cone circuit. A typical closed-circuit test facility incorporating a Mark 6 tray assembly is shown in Fig. 18.

The capacity of a Mark 6 tray assembly is in the range 3 to 5 t/h of solids and, in a closed-circuit facility like that shown in Fig. 18, individual tests can be conducted on samples as small as 25 kg. Test programmes have been carried out using the Mark 6 tray test facility t predict the performance of multi-stage cone circuits. A test programme aimed at providing the data for the design of a four-stage cone circuit (primary, cleaner, scavenger, and recleaner) is shown in Fig. 19.

The data required for the design of the cone circuit can be obtained by this procedure from a sample of 1400 kg. If a full-sized cone concentrator were used to generate the same data, a sample of between 20 and 30 t would be required.

Comparative results for mineral sands obtained from tests on a closed-circuit tray assembly and from an actual production 4DS cone are shown in Fig. 20. The tray system in this case contained twelve concentrating elements, the same number as the 4DS cone, but the internal flow arrangement was a matrix system. Later

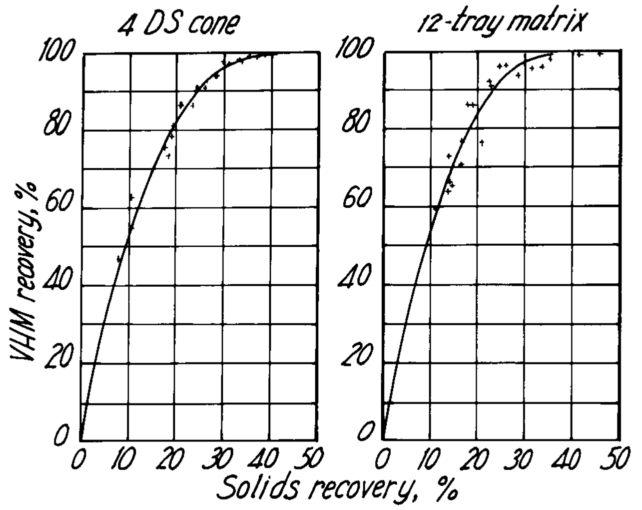

Fig. 20—Comparative results on mineral sands

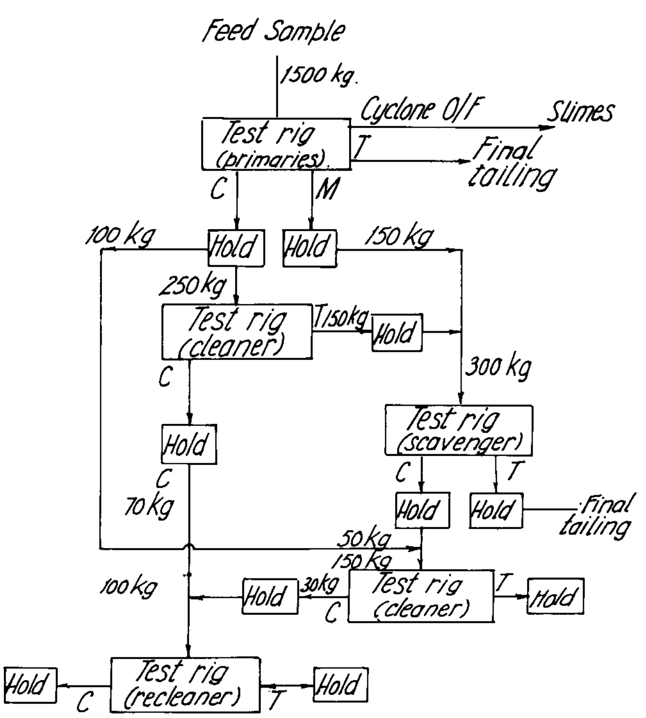

Fig. 19—Test programme for a four-stage circuit using the tray rig

TABLE IV
WESTERN MINING CORP., KAMBALDA
COMPARATIVE TEST RESULTS

| Test | Product | Distn % by mass | Au assay g/t | Au distn % |
|---|---|---|---|---|
| T2* | Conct. 1 | 23,59 | 72,00 | 78,66 |
| | Conct. 2 | 9,40 | 8,80 | 3,79 |
| | Conct. 3 | 7,06 | 7,40 | 2,39 |
| | Conct. 4 | 9,32 | 7,40 | 3,16 |
| | Tail. | 50,63 | 5,18 | 12,00 |
| | Head | 100,00 | 21,83 | 100,00 |
| | Conct. 1 | 13,47 | 11,40 | 21,50 |
| | Conct. 2 | 6,21 | 7,96 | 6,87 |
| | Conct. 3 | 15,37 | 7,30 | 15,72 |
| T3† | Conct. 4 | 19,03 | 8,60 | 22,93 |
| | Tail. | 45,92 | 5,13 | 32,98 |
| | Head | 100,00 | 7,14 | 100,00 |
| | Conct. 1 | 15,65 | 22,0 | 66,50 |
| | Middling | 10,43 | 6,0 | 12,09 |
| in‡ | Tail. | 73,92 | 1,50 | 21,41 |
| plant | Head | 100,00 | 5,18 | 100,00 |

*4DS Mark 6 tray system
†DSS.DS primary cone in plant
‡Feed comprises:
mill discharge 2,8 g/t
cone middling 6,0 g/t
strake tails 82,8 g/t

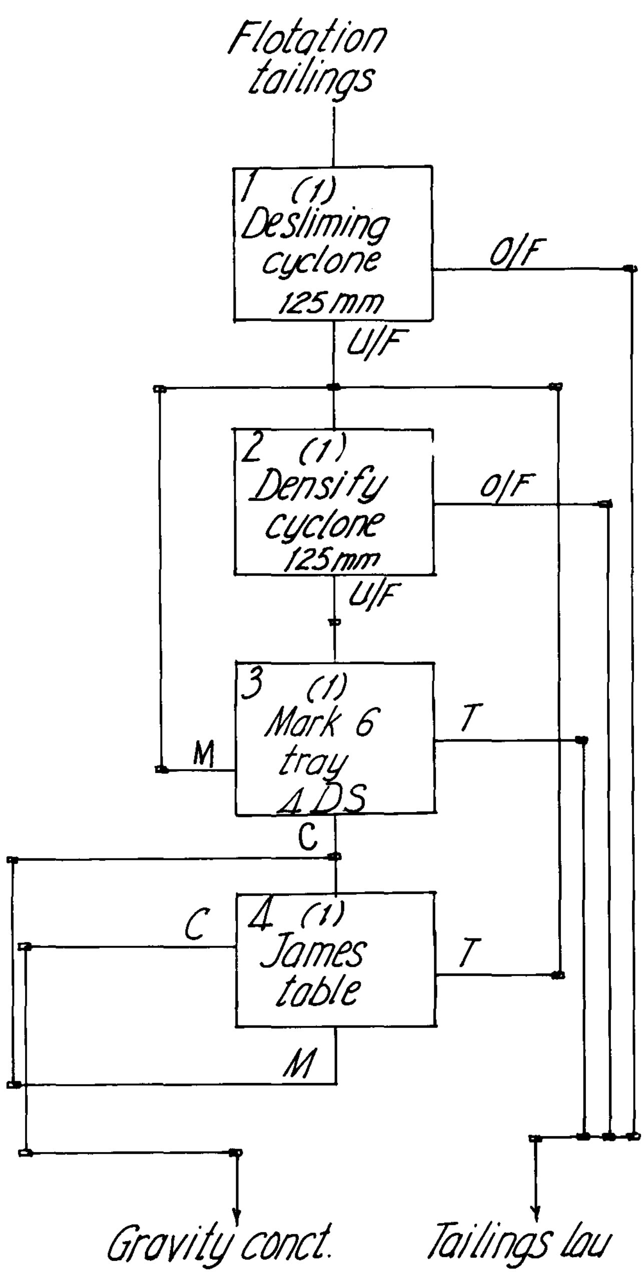


**Fig. 21—Circuit at Roan Consolidated Mines, Mufulira**

testwork has shown that the matrix tray system has the same performance as the 4DS tray configuration. The results of tests on Mark 6 trays are now used with confidence in the prediction of the performance of cone circuits on mineral sands. Western Mining Corporation installed a gold gravity circuit on one of the mill lines in its Kambalda concentrator based on the test results obtained from a 4DS Mark 6 tray system. The test and actual plant results for the primary stage of the circuit are shown in Table IV.

The discrepancy between the results of Tests T2 and T3 in Table IV was found by mineralogical examination to be due to the presence of a background level of very fine gold. A high recovery of coarse gold was obtained. While the head grades of the material treated in the production circuit have been much lower than those indicated by the sample tested, a variation in gold recovery from the circuit is observed depending on the proportion of coarse to fine gold present. Overall gold recoveries, into strake concentrates, in the range 35 to 50 per cent have been recorded from head grades of 2 to 3 g/t.

The Mark 6 tray assembly is also suitable for use in the evaluation of the cone concentrator for open-circuit installations. Such an installation has been operating satisfactorily at the Mufulira concentrator of Roan Consolidated Mines in Zambia. This pilot plant was commissioned to determine whether there were valuable heavy minerals in the tailings from the copper-flotation circuit and, if so, whether they could be recovered economically by gravity concentration. The circuit is shown in Fig. 21. A portion of the current tailings is continuously cut out and passed through the pilot plant, and the table concentrates are collected for analysis.

## General Flowsheet Design

Tests that are not designed as part of an overall sequence aimed at simulation models usually have clearly defined objectives, and very little extra data processing is required beyond simple calculation of the tonnage flows, percentage solids, and assays. Some simple statistical tests are sometimes useful, for example to detect whether the results obtained from one treatment or one batch of ore are significantly different from another set of results.

Estimates of overall circuit performances are usually obtained by setting up individual tests to correspond roughly with the anticipated duties in the proposed plant and using the results as a guide. Difficulties always arise in preparing a balanced flowsheet estimate because of incompatible grades from the tests and the problems posed by recycle flows. A general flowsheet programme was developed for the purpose of balancing pilot-plant and test-rig data, and it operates by adjusting the absolute magnitudes of the solids, water, and mineral flows while maintaining the same proportional values in the products from each element of the circuits. Incompatible grades, unbalanced flows, or lack of test data can be adjusted or compensated for. An example of programme operation is shown in Tables V to VII and Fig. 22.

When computer facilities are not available to run programmes such as that described, the circuits can be balanced by a method requiring only a slide rule or four-function calculator.

The first step in the procedure for balancing throughput is to estimate the initial performance for each unit in the flowsheet and to mark the data on the flow diagram, producing (usually) a number of flow/grade imbalances. A series of simple calculations is then performed to display the proportional splits to the products for each 100 units of feed solids. When the effects of changes in tonnage have been established at all points in the circuit, the tonnages can be brought into balance by applying the corrections in sequence on a *pro rata* basis. Once the flowsheet tonnages are in balance, other parameters such as grade or liquid : solids ratios must usually be adjusted before a full set of new performance calculations is initiated.

**TABLE V**

**PROGRAMME FOR SET FLOW VALUES**

EXAMPLE CIRCUIT

| ELEMENT NO. | TITLE | MACHINE TYPE | UNIT TYPE | NUM OFF | FEED %SOL. | CONS DILN | DESTINATIONS P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CYCLONES | | | 0 | 0 | 0 | 2 | 0 | 0 | 0 | -3 |
| 2 | ROUGHER | CONES | 4DS | 12 | 60 | 240 | 4 | 4 | 4 | 3 | -2 |
| 3 | MIDS-SCAV | CONES | 4DS | 6 | 60 | 120 | 4 | 4 | 4 | 3 | -2 |
| 4 | CLEANER | CONES | 2DSS-DS | 6 | 60 | 120 | 5 | 5 | 4 | 0 | 3 |
| 5 | RECLEANER | CONES | 2DSS-DS | 2 | 60 | 40 | -1 | 6 | 5 | 0 | 4 |
| 6 | SPIRALS | MK.6 | D | 30 | 35 | 60 | -1 | 0 | 0 | 0 | 5 |

SET FLOW VALUES (W INDICATES TPH WATER)

| NO. | ELEMENT | PRODUCT | TPH | %SOL | %HM |
|---|---|---|---|---|---|
| 1 | CYCLONES | Uflow | 100.00 | 65.00 | 5.00 |
| | | Oflow | 5.00 | 2.55 | 0.80 |
| | | Feed | 0.00 | 0.00 | 0.00 |
| 2 | ROUGHER | Con.1 | 7.00 | 69.50 | 21.00 |
| | CONES | Con.2 | 7.00 | 68.00 | 20.00 |
| | 4DS | Con.3 | 6.00 | 66.33 | 18.17 |
| | | Con.4 | 8.80 | 66.00 | 3.30 |
| | | Tails | 51.20 | 48.00 | 0.29 |
| | | Feed | 0.00 | 0.00 | 0.00 |
| 3 | MIDS-SCAV | Con.1 | 7.00 | 68.00 | 5.50 |
| | CONES | Con.2 | 5.50 | 66.30 | 4.10 |
| | 4DS | Con.3 | 4.00 | 62.40 | 2.48 |
| | | Mids | 9.00 | 64.00 | 1.35 |
| | | Tails | 46.50 | 46.00 | 0.29 |
| | | Feed | 0.00 | 0.00 | 0.00 |
| 4 | CLEANER | Con.1 | 10.00 | 71.00 | 50.00 |
| | CONES | Con.2 | 9.00 | 68.92 | 45.04 |
| | 2DSS-DS | Mids | 12.00 | 68.00 | 12.71 |
| | | Tails | 62.00 | 50.00 | 0.53 |
| | | Feed | 0.00 | 0.00 | 0.00 |
| 5 | RECLEANER | Con.1 | 12.50 | 70.00 | 97.00 |
| | CONES | Con.2 | 30.00 | 68.00 | 68.85 |
| | 2DSS-DS | Mids | 10.00 | 66.00 | 52.63 |
| | | Tails | 22.50 | 50.00 | 6.32 |
| | | Feed | 0.00 | 0.00 | 0.00 |
| 6 | SPIRALS | Con.1 | 1.25 | 45.00 | 96.02 |
| | MK.6 | Tails | 1.75 | 30.00 | 48.23 |
| | D | Feed | 0.00 | 0.00 | 0.00 |
| 7 | CIRCUIT | Feed | 1050.00 | 30.00 | 4.80 |

TABLE VI

PROGRAMME FOR BALANCED FLOW VALUES

EXAMPLE CIRCUIT

BALANCED FLOW VALUES

| NO. | TITLE | PRODUCT | %WT. | TPH | %SOL | %HM | DISTN |
|---|---|---|---|---|---|---|---|
| 1 | CYCLONES | Uflow | 95.24 | 1000.00 | 65.00 | 5.00 | 99.21 |
| | | Oflow | 4.76 | 50.00 | 2.55 | 0.80 | 0.79 |
| | | Feed | 100.00 | 1050.00 | 30.00 | 4.80 | 100.00 |
| 2 | ROUGHER CONES 4DS | Con.1 | 8.75 | 87.50 | 68.56 | 19.10 | 33.43 |
| | | Con.2 | 8.75 | 87.50 | 67.04 | 18.19 | 31.84 |
| | | Con.3 | 7.50 | 75.00 | 65.34 | 16.53 | 24.79 |
| | | Con.4 | 11.00 | 110.00 | 65.01 | 3.00 | 6.60 |
| | | Tails | 64.00 | 640.00 | 46.90 | 0.26 | 3.33 |
| | | Feed | 100.00 | 1000.00 | 60.00 | 5.00 | 100.00 |
| 3 | MIDS-SCAV CONES 4DS | Con.1 | 9.72 | 46.67 | 68.69 | 5.02 | 39.93 |
| | | Con.2 | 7.64 | 36.67 | 67.01 | 3.74 | 23.39 |
| | | Con.3 | 5.56 | 26.67 | 63.15 | 2.26 | 10.29 |
| | | Mids | 12.50 | 60.00 | 64.74 | 1.23 | 12.60 |
| | | Tails | 64.58 | 310.00 | 46.80 | 0.26 | 13.79 |
| | | Feed | 100.00 | 480.00 | 60.00 | 1.22 | 100.00 |
| 4 | CLEANER CONES 2DSS-DS | Con.1 | 10.75 | 50.00 | 68.33 | 55.57 | 45.84 |
| | | Con.2 | 9.68 | 45.00 | 66.15 | 50.06 | 37.16 |
| | | Mids | 12.90 | 60.00 | 65.19 | 14.13 | 13.98 |
| | | Tails | 66.67 | 310.00 | 46.84 | 0.59 | 3.01 |
| | | Feed | 100.00 | 465.00 | 60.00 | 13.04 | 100.00 |
| 5 | RECLEANER CONES 2DSS-DS | Con.1 | 16.67 | 25.00 | 61.10 | 95.04 | 30.72 |
| | | Con.2 | 40.00 | 60.00 | 59.86 | 67.46 | 52.34 |
| | | Mids | 13.33 | 20.00 | 56.65 | 51.57 | 13.34 |
| | | Tails | 30.00 | 45.00 | 40.24 | 6.19 | 3.60 |
| | | Feed | 100.00 | 150.00 | 60.00 | 51.56 | 100.00 |
| 6 | SPIRALS MK.6 D | Con.1 | 41.67 | 25.00 | 34.88 | 95.06 | 58.71 |
| | | Tails | 58.33 | 35.00 | 21.91 | 47.75 | 41.29 |
| | | Feed | 100.00 | 60.00 | 35.00 | 67.46 | 100.00 |
| 7 | CIRCUIT | Prd.1 | 4.76 | 50.00 | 44.41 | 95.05 | 94.30 |
| | | Prd.2 | 90.48 | 950.00 | 46.87 | 0.26 | 4.91 |
| | | Prd.3 | 4.76 | 50.00 | 2.55 | 0.80 | 0.79 |
| | | Feed | 100.00 | 1050.00 | 30.00 | 4.80 | 100.00 |

The grades of the flows can be brought into balance in one of two ways:

(a) adjustment of the grades found during the previous round of overall performance calculations on a ratio basis by use of the balanced tonnages;

(b) adjustment of the grades simultaneously with the tonnages using the relaxation approach.

It will usually be found that option (b) creates too many calculations and figures to be recorded: option (a) therefore represents the better choice.

An example illustrating the steps in balancing a flowsheet by this method is shown in Fig. 23.


## ACKNOWLEDGEMENTS

The authors acknowledge with sincere thanks the cooperation of the management and staff of all the companies whose plant flowsheets and performance details are quoted and, in particular, the management and staff of Western Mining Corporation and Mining Corporation, who generously provided and permitted the publication of unreleased test and production data. The permission of Mineral Deposits Limited to publish this paper is also gratefully acknowledged. The opinions expressed in the paper are those of the authors and do not necessarily reflect the opinions of Mineral Deposits Limited or its client companies referred to in the text.

## TABLE VII

### PROGRAMME FOR BALANCED ADDITIONAL FLOW VALUES

Values = 100 %HM     S.G. Values = 4.40     Gangue = 2.70

BALANCED FLOW VALUES

| ELEMENT NO. | ELEMENT TITLE | PRODUCT | S.G. | SOLIDS TPH | %SOL w/w | DILN TPH | WATER M3/HR | PULP M3/HR |
|---|---|---|---|---|---|---|---|---|
| 1 | CYCLONES | Uflow | 2.79 | 1000.00 | 65.00 | 0.00 | 538.46 | 897.52 |
| | | Oflow | 2.71 | 50.00 | 2.55 | 0.00 | 1911.54 | 1929.97 |
| | | Feed | 2.78 | 1050.00 | 30.00 | 0.00 | 2450.00 | 2827.48 |
| | | Sump | | | | | 0.00 | Balance |
| 2 | ROUGHER CONES 4DS | Con.1 | 3.02 | 87.50 | 68.56 | 10.62 | 40.13 | 69.05 |
| | | Con.2 | 3.01 | 87.50 | 67.04 | 11.39 | 43.03 | 72.10 |
| | | Con.3 | 2.98 | 75.00 | 65.34 | 10.53 | 39.78 | 64.94 |
| | | Con.4 | 2.75 | 110.00 | 65.01 | 15.67 | 59.22 | 99.20 |
| | | Tails | 2.70 | 640.00 | 46.90 | 191.78 | 724.51 | 961.16 |
| | | Feed | 2.79 | 1000.00 | 60.00 | 240.00 | 666.67 | 1025.73 |
| | | Sump | | | | | -128.21 | Deficit |
| 3 | MIDS-SCAV CONES 4DS | Con.1 | 2.79 | 46.67 | 68.69 | 5.80 | 21.27 | 38.02 |
| | | Con.2 | 2.76 | 36.67 | 67.01 | 4.92 | 18.05 | 31.32 |
| | | Con.3 | 2.74 | 26.67 | 63.15 | 4.24 | 15.56 | 25.30 |
| | | Mids | 2.72 | 60.00 | 64.74 | 8.91 | 32.69 | 54.74 |
| | | Tails | 2.70 | 310.00 | 46.80 | 96.12 | 352.44 | 467.06 |
| | | Feed | 2.72 | 480.00 | 60.00 | 120.00 | 320.00 | 496.42 |
| | | Sump | | | | | +123.66 | Surplus |
| 4 | CLEANER CONES 2DSS-DS | Con.1 | 3.64 | 50.00 | 68.33 | 6.47 | 23.17 | 36.89 |
| | | Con.2 | 3.55 | 45.00 | 66.15 | 6.43 | 23.03 | 35.70 |
| | | Mids | 2.94 | 60.00 | 65.19 | 8.94 | 32.04 | 52.45 |
| | | Tails | 2.71 | 310.00 | 46.84 | 98.17 | 351.76 | 466.15 |
| | | Feed | 2.92 | 465.00 | 60.00 | 120.00 | 310.00 | 469.16 |
| | | Sump | | | | | -33.30 | Deficit |
| 5 | RECLEANER CONES 2DSS-DS | Con.1 | 4.32 | 25.00 | 61.10 | 4.55 | 15.91 | 21.71 |
| | | Con.2 | 3.85 | 60.00 | 58.86 | 11.98 | 41.94 | 57.54 |
| | | Mids | 3.58 | 20.00 | 56.65 | 4.37 | 15.30 | 20.90 |
| | | Tails | 2.81 | 45.00 | 40.24 | 19.10 | 66.84 | 82.88 |
| | | Feed | 3.58 | 150.00 | 60.00 | 40.00 | 100.00 | 141.94 |
| | | Sump | | | | | +86.26 | Surplus |
| 6 | SPIRALS MK.6 D | Con.1 | 4.32 | 25.00 | 34.88 | 16.34 | 45.68 | 52.47 |
| | | Tails | 3.51 | 35.00 | 21.91 | 43.66 | 124.75 | 134.72 |
| | | Feed | 3.85 | 60.00 | 35.00 | 60.00 | 111.43 | 127.03 |
| | | Sump | | | | | -69.49 | Deficit |
| 7 | CIRCUIT | Prd.1 | 4.32 | 50.00 | 44.41 | - | 62.59 | 74.18 |
| | | Prd.2 | 2.70 | 950.00 | 46.87 | - | 1076.95 | 1428.22 |
| | | Prd.3 | 2.71 | 50.00 | 2.55 | - | 1911.54 | 1929.97 |
| | | Feed | 2.78 | 1050.00 | 30.00 | - | 2450.00 | 2827.48 |
| | | Sump | | | | | -21.08 | Deficit |

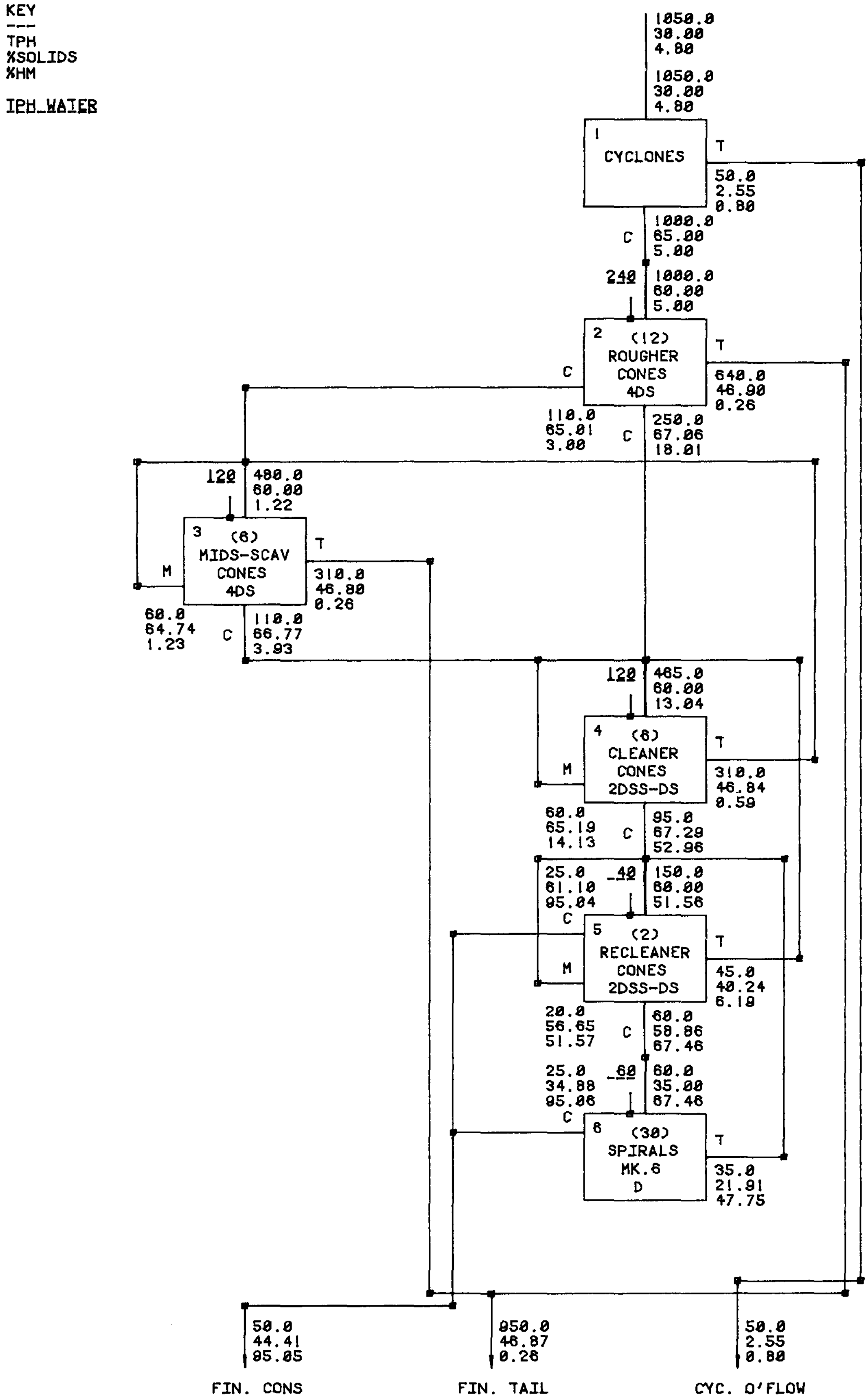


**Fig. 22—An example circuit**

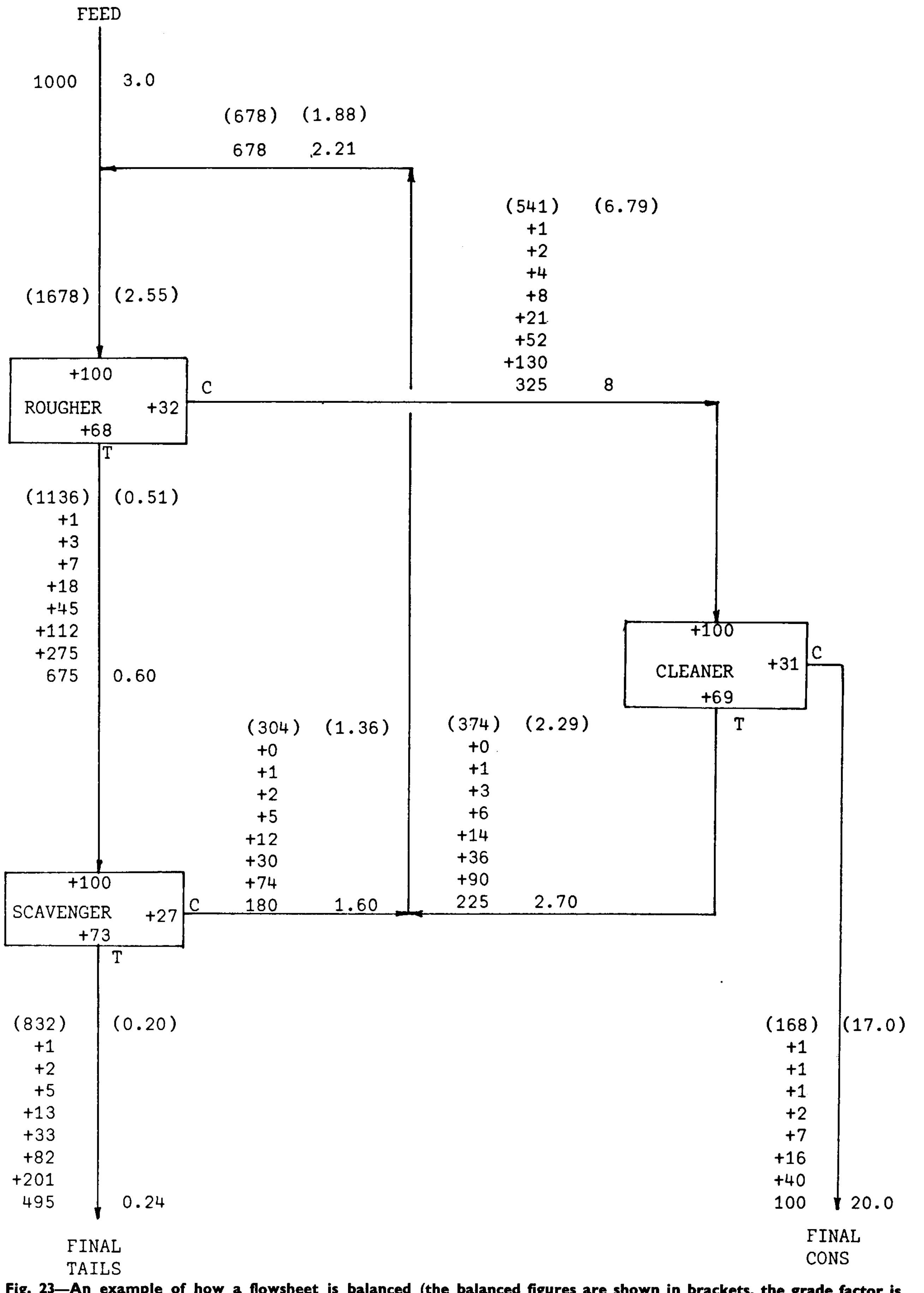


**Fig. 23—An example of how a flowsheet is balanced (the balanced figures are shown in brackets, the grade factor is 0,8485)**

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# Sampling in the mineral industry

A three-day School on Sampling in the Mineral Industry will be presented by the Southern Transvaal Section of the South African Chemical Institute from 30th August to 1st September, 1982.

The aim of the school will be to present a course that will give participants a thorough understanding of the theory of sampling in the mineral industry. Strong emphasis will be placed on practical applications, and it is envisaged that the lectures will be complemented by case studies and field visits during the afternoons.

The course will be of benefit to all chemists, metallurgists, geologists, and managers who wish to obtain an understanding of this complex and exasperating subject.

The convener, Fanie Geldenhuis, can be contacted at (011) 29–7486 for further details.

# Design of underground excavations

The Institution of Mining and Metallurgy–Royal School of Mines residential course entitled 'Engineering rock mechanics for underground excavation design', which will be presented by Dr E. Hoek and Professor E. T. Brown at the Bedford Hotel, Brighton, between 4th and 7th June, 1982, is designed to provide practising civil and mining engineers with instruction in the application of modern rock mechanics methods to the design of underground excavations in rock. Emphasis will be placed on the design of permanent underground excavations, such as tunnels and caverns, and on those underground mining excavations that are of a permanent or semi-permanent nature, including large open stopes. The course will consist of a combination of lectures and workshop classes in which practice will be given in the use of the techniques introduced to solve sample problems.

The textbook *Underground excavations in rock*, written by the two course presenters and published by the IMM, will serve as the basis of the course; a copy of this book will be included in the set of course materials to be provided to every registrant. The basic material in this book will be supplemented by more up-to-date information and by illustrations drawn from the presenters' recent practical experience on mining and civil-engineering projects in various parts of the world.

Topics to be discussed will include the general approach to underground excavation design; geological data collection; graphical methods of data presentation and analysis; the application of rock mass classification schemes; the strength of rocks and rock masses; *in situ* states of stress; fundamentals of elastic stress analysis; design against stress-induced failures; pillar design; design against structurally controlled failures including pre-reinforcement; methods of estimating support requirements; rock-support interaction analyses; the New Austrian Tunnelling Method; practical aspects of support techniques, including steel sets, rockbolts, cables, shotcrete, mesh; instrumentation and monitoring.

Application forms for the course and further details are available from the Secretary, The Institution of Mining and Metallurgy, 44 Portland Place, London WIN 4BR, England. Telephone 01–580 3802. Telex 261410.