GRAVITY CONCENTRATION SYSTEMS IN GOLD ORE PROCESSING

by

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ABSTRACT

The use of gravity concentration is, and has always been, the conventional primary method for gold recovery from alluvial deposits. The development of high capacity cone concentrators and metallurgically efficient wash-waterless spiral separators has had some impact in the technology for alluvial gold processing, but perhaps more significantly has led to the relatively recent use of this gravity concentration technology in grinding circuits of hard rock ore for "coarse" gold removal and for scavenging gold locked in sulphides from cyanidation tailings streams.

Gravity concentration systems are relatively low-cost, non-polluting and energy efficient; and their judicial use in gold treatment plants can significantly reduce overall capital and operating costs.

The application of modern gravity concentration technology to hard-rock and alluvial gold ore treatment is discussed. Flowsheets and test and operating data from a number of gold processing operations incorporating gravity concentration treatment are presented.

INTRODUCTION

The gravity concentration of gold is among the earliest recorded metallurgical extraction systems.

Although gravity concentration has always dominated the recovery of gold from alluvial deposits, the development of froth flotation and leaching techniques earlier this century led to the digression of interest away from gravity separation systems for gold recovery from hard-rock gold deposits. This digression was due in part to the fashion of the day; but also resulted from the reluctance of operators to install gravity concentration systems due to the relatively low capacity of the unit processes available, and the inherent security problems associated with such systems. This situation was aggravated by the general decline of the gold industry since the 1930s, resulting from a fixed gold price, lower head grades and increasingly higher costs of establishing and operating gold mines. Over this period of decline in the gold industry, there were technological advances that could have improved efficiency in the gold industry (particularly alluvial gold). However, they were not widely adopted due largely to the economic constraints outlined above.

The last decade, however, has seen a dramatic resurgence of interest in the use of gravity separation in the gold industry generally. This resurgence of interest, although primarily motivated by the rapid escalation of gold prices, has also been due to the availability of newer and more efficient technology. Other aspects of significance in these developments are:

1. Increasing energy costs,
2. Increasing reagent costs for both flotation and leaching systems,
3. an educational evolution in the understanding of new-generation gravity technology, particularly in terms of its potential application in areas complementing other mineral processing systems, and
4. Increasing awareness of environmental issues, and subsequent public and governmental pressure on the mining industry to consider non-polluting technologies.

TRADITIONAL GRAVITY SEPARATION TECHNOLOGY FOR GOLD

The traditional or conventional gold processing techniques have always had a strong gravity component, especially in the alluvial or placer-type deposits. The high specific gravity of gold compared with the gangue minerals has made gravity separation attractive for gold recovery. It is not the intention here to expand on the theoretical aspects of gravity concentration, as this is well documented (Taggart, 1945; Mills, 1978). Nevertheless, it is worth noting that despite the high specific gravity of gold, the effects of particle shape and the hydrophobicity of fine gold particles can significantly reduce the ostensible specific gravity advantage for gold separation systems. For alluvial gold in particular, the particle shape effect resulting from the malleability of gold and the consequent ubiquitous occurrence of flattened gold particles, is significant to processing requirements.

The most widely used gravity equipment for the recovery of free gold from both alluvial and free-milling ores has been jigs, riffled tables, shaking tables and sluices.

For alluvial gold recovery, sluices were the first type of gravity concentrator with any significant capacity. Their simplicity reflected the ease of recovery of coarse gold, which was the primary objective of earlier processing sytems. The characteristically wide size distribution fed to early sluices necessitated deep channels with fast-flowing pulp to ensure the transportation of the largest sized particles. This arrangement, where boulders and fines were treated together, gave little chance for any fine gold to be recovered. The screening out of gross oversize and transition to the more effective riffled tables improved the probability for fine gold recovery, but because sampling and analytical techniques were poor, the loss of fine gold was frequently not recognised.

The introduction of jigs, having the advantage of allowing continuous processing, may have resulted in greater metallurgical efficiency. However, the limited data available on jig performances indicates an inability to adequately recover gold below 100 microns, with performance falling off significantly below 200 microns (Fricker, 1984). The relatively recently-developed circular jig may be marginally more efficient than rectangular jigs, in that the diminishing radial velocity enables the outer portion of the jig to perform a scavenging function (Tjoe, 1978).

Shaking tables have been used and, like jigs, have the advantage of being a continuous process. Shaking tables can also exploit the naturally flat shape of gold particles in many alluvial deposits. These flat particles tend to remain suspended in the jig bed, and can therefore be lost to tailings. Contrarily, for table operation the large contact area of the flat particles enhances the drag forces on a shaking table, and therefore tends to improve the metallurgical performance. Notwithstanding this factor, the natural hydrophobicity of fine gold particles can be more significant in decreasing the metallurgical performance of shaking tables, as fine gold particles can tend to float across the top of the bed (Feather and Koen, 1973). Also, shaking tables have the disadvantage of requiring a large plant area and a stable platform.

Since the widespread use of cyanidation and/or flotation for the treatment of milled ores, the gravity concentration processes used in these operations have been confined to the removal of coarse free gold using equipment such as strakes, jigs, tables and Johnson concentrators. There have been no recent developments in this area, with the exception of the advent and use of continuous strake tables. The lack of motivation for developing new equipment for this duty is due largely to the fact that the metallurgical efficiency of these unit processes is not critical to the overall operation, as "lost" values are "scavenged" by subsequent cyanidation.

In the past, conventional metallurgical balances in alluvial gold operations have either not been feasible or have been considered too difficult due to the problems associated with sampling (Fricker, 1984). In these instances, performance has been assessed by comparing production to estimates based on drillhole data (Fricker, 1976). Apart from the inherent sampling error problems associated with these methods, the drilling techniques used and the methods of evaluation and recovery of the gold values from drilling samples resulted, at times, in dramatically understated levels of gold occurring at finer sizes (particularly <100 microns) in alluvial deposits; albeit largely not recoverable by conventional gravity systems.

The more recent use of better techniques has enabled fine alluvial gold to be more accurately assessed and has led to an awareness in certain instances of significant fine gold losses occurring in alluvial operations. Moreover, the potential exists for substantially increased gold production (without increased throughput) provided cost-effective technology is available or can be developed for the recovery of fine alluvial gold.

Furthermore, the availability of such technology will facilitate the exploitation of previously uneconomic alluvial gold deposits.

It is not surprising then that the area of gravity separation technology having the most recent impact on gold metallurgical practices is that of fine particle beneficiation.

NEW TECHNOLOGY FOR FINE GOLD RECOVERY

Economic forces in the Australian mineral sands industry in the 1960s caused by falling ore grades led to the development of gravity separation equipment; specifically the Reichert cone concentrator and the refinement of the spiral separator, originally developed by Humphreys. Both cones and spiral have since undergone continuous further development, and are now used in the gravity beneficiation of a wide variety of ores, including gold (both alluvial and hard-rock).

CONE CONCENTRATORS

The Reichert cone concentrator is a high capacity, low cost gravity concentrator developed by Mineral Deposits Limited of Gold Coast, Queensland, Australia (Graves, 1973; Ferree & Terrill, 1978). Designed for the treatment of particulate material generally finer than 2mm in size and to recover fine heavy mineral particles down to 38 microns, the cone concentrator effectively consists of a series of circular pinched sluices (see Figure 1). The separation mechanism involves a combination of hindered settling and intergranular trickling resulting in a stratified flowing bed in which the heavy and fine particles are concentrated at the bottom of the pulp stream and are removed by an annular slot.

The two metre diameter model of the Reichert cone has a design throughput of 60 to 80 tph per unit. A higher capacity 3.5 metre diameter Reichert cone concentrator unit has recently been developed. The 3.5 metre cone concentrator is a derivative of the two metre unit, but has the benefits of higher unit capacity (up to 300 tph) and longer stratification length.

SPIRAL SEPARATORS

The use of spirals on alluvial gold deposits has been known for a number of years, spirals having been originally designed for beach sands and later adapted for other minerals (Balderson, 1982). The early spirals were not entirely suited for gold recovery, and although reasonably successful down to 75 microns, the washwater additons tended to wash fine gold to tailings.

The recently available washwaterless spirals have significantly effected the performances attainable. A good example is the Reichert Mark 7A spiral (See Figure 2), which incorporates several features beneficial to gold recovery. The spiral profile is, in fact, a compound profile which is specifically designed for low grade heavy mineral ores (<5% hm). With no washwater, the fines problem is lessened. A single set of ganged splitters at the end of each of the troughs (up to three per column).reduces both operator attention requirements and potential gold traps. The ganged nature of the splitter arrangement also reduces piping and laundering requirements.

Indicative spiral performance on alluvial gold is given in Table 1, which shows two sets of test results from the United States on Mark 7A spirals (Robinson and Ferree, 1983):

TABLE 1
Spiral Performance on Alluvial Gold Ore

Crushed Gravel, California.

	Wt. Distn %	Assay (oz/ton)	Assay (g/t)	Au Distn (%)
Con	7.4	0.609	18.64	90.7
Mid	46.0	0.007	0.21	6.5
Tail	46.6	0.003	0.09	2.8
Feed	100.0	0.050	1.53	100.0

Feed rate: 2 tph solids/spiral start

Snake River Gold - Idaho

	Wt. Distn %	mg of Au	% Au Distn
Con	2.20	17.58	92.1
Tails	97.80	1.51	7.9
Feed	100.0	19.09	100.0

For both feeds, all the gold was minus 150 microns

HYDROCYCLONE SYSTEMS

Water washing cyclones have been proposed for gold beneficiation (Visman, 1966). However, their recent disfavour in the Australian coal industry compared with spiral separators (Hornsby et al, 1983) does not augur well for any significant impact of water washing cyclones in gold beneficiation practice.

Similar in concept to water washing cyclones are the circulating bed classifier (CBC) cyclones produced by Amberger Kaolinwerke GmbH (AKW) (Trawinski, 1982). These flat-bottomed hydrocyclone units offer the advantages of high classification efficiencies under fluctuating feed conditions while maintaining constant high underflow densities. They can also be operated at high cut sizes compared with conventional cylones and the concentrating effects on high specific gravity minerals are greater than those obtained for conventional conical hydrocyclones.

CBC cyclones offer, therefore, a convenient classification/concentration system that will no doubt find application both in alluvial gold processing for feed preparation (desliming, densification and concentration) prior to fine gravity circuits, and in grinding circuits treating hard-rock gold ores. Indeed, in the Soviet Union similar machines have had considerable impact for the recovery fo fine gold (Anon., 1981).

Dense media separation cyclones and their derivative versions, including the "Dyna Whirlpool" (Wills and Lewis, 1980) and "Tri Flow" separators (Dessinibus, 1982) are now widely used in the coal and tin industries. Their high separation efficiencies are, however, generally confined to the treatment of material above 0.5mm. Although recent developments in the Republic of South Africa have led to suggestions that consideration will be given to the use of dense media cyclones at finer sizes for coal, (van der Walt et al, 1981) the relatively high capital and operating costs of such systems mean that it is unlikely they will find application for the treatment of gold ores.

OTHER SYSTEMS

Centrifugal gravity systems, including the Gilkey Bowl (Barber, 1976) [a centrifugal amalgamator similar to the Lorenston concentrator (MacKenzie, 1937)] developed in Columbia, and the Knelson concentrator have proven effective for fine gold recovery. The Knelson concentrator has won acceptance into commercial use in several locations. The Gilkey Bowl and the Knelson concentrator both suffer from the disadvantage of being discontinuous processes, and like plane tables, must inherently exhibit continuously reducing metallurgical performance with time between clean-ups. Furthermore, the Knelson concentrator will have considerably higher operating costs than, for example, a spiral circuit of equivalent capacity; due to:

1. the requirement of considerable quantities of very clean water for effective operation, and
2. high maintenance of mechanical parts moving in a very abrasive environment (sand slurry).

Ultrafine or slimes gravity concentrators, including the GEC duplex concentrator (Anon., 1983) and the Bartles-Mosely table and cross belt separator (Mills and Burt, 1979), all relatively recently developed largely for fine cassiterite recovery, may find application in fine gold beneficiation. Generally, however, these devices are high-cost, low-throughput systems better suited to the treatment of relatively high-grade feedstocks.

APPLICATION AREAS FOR NEW TECHNOLOGY

ALLUVIAL SYSTEMS

Alluvial gold operations using the traditional methods tend to use simple flowsheets, rarely going beyond two or three stages of concentration. Many operations are dredge-based and hence space and the ability to handle less stable conditions are important. Furthermore, any gold operation has potential security problems, which may increase with complicated circuitry. Most importantly, however, the easy recovery of coarse gold has not encouraged ingenuity or experiment in circuitry as has been the case in, for example, the tin industry.

By way of example, Figure 3 shows a typical example of an alluvial system from New Zealand. The wisdom of using tables to treat the jig concentrates in this circuit is questionable as the intrinsically greater efficiency of jigs compared with that of plane tables is lost in such an arrangement. Nevertheless, such practices have been commonplace in alluvial gold systems.

The use of new technology specifically to improve fine gold recoveries will, of course, be dependent upon the particular characteristics of the orebody and its situation. However, the basic concepts are demonstrated in the outline flowsheet shown in Figure 4. The conceptual flowsheet incorporates jigging for coarse gold recovery, followed by several stages of gravity concentration using Reichert cone concentrators and spiral separators for fine gold recovery from screened jig tailings. The flowsheet also includes classification for slimes removal and adequate coarse and fine sizing to ensure optimised unit performance on each gravity stage. Middlings streams are recirculated to accommodate circuit fluctuations and thereby maintain good metallurgical performance. Tailings are rejected from both cone stages and a final gravity concentrate is shown to be generated from both spiral stages. The gravity concentrate may be processed further; using, for example, amalgamation for final gold recovery.

Examples

Over the past few years, several Reichert cones have been installed in alluvial operations to recover fine gold. A typical operation is on the Snake River in Southern Idaho, U.S.A. In this operation gold (which averages about 0.1 gm/tonne in the gravels) is recovered from a fine screen fraction using a Reichert cone in conjunction with a conventional shaking table. Gold recoveries in excess of 85 percent are reported, with 44 percent of the recovered gold finer than 75 microns (Ferree, 1981).

Within the last 18 months, several alluvial gold plants utilising Reichert Mark 7A spirals only for fine gold recovery have been built in the U.S.A. One such plant in Grass Valley, California, is on the back end of a gravel plant and incorporates 12 three-start and two single-start Reichert Mark 7A spirals.

GRINDING CIRCUITS

Many hard-rock gold ore treatment plants incorporate gravity concentration early in the circuit to recover the coarser particles of liberated gold minerals early in the circuit. Without such a system of coarse gold removal, requisite cyanidation times can be prohibitively long, and the loss of gold contained in larger highly-refractory or "rusty" (surface-coated) gold mineral particles which may fail to dissolve completely in cyanide solution results in a lowering of overall gold recoveries (Feather and Koen, 1973; Bath et al, 1973).

The incorporation of gravity concentration in gold-grinding circuits, therefore, can result in a reduction in the size of downstream plant requirements with substantial capital and operating cost savings, with accompanying benefits of improved overall recovery.

Furthermore, security problem areas in the plant, specifically the final gravity stage, can be readily isolated.

Although the metallurgical efficiency of gravity concentration in gold grinding circuits is not critical, various documented cases in Australia and South Africa report recoveries of gold by gravity methods over the range 11-90 percent (Elvey and Woodcock, 1967; Douglas and Moir, 1961).

Gravity concentration in grinding circuits is invariably multi-staged with the tailings being returned for regrind and a gravity concentrate obtained and subjected to amalgamation or intensive cyanidation for gold recovery. Current South African practice for gravity concentration in grinding circuits has favoured Johnson drum concentrators followed by continuous strakes (Loveday and Forbes, 1982). However, the use of Reichert cone concentrators and new-generation spiral separators with their inherent advantages of relatively high capacity and low energy consumption and maintenance (having no moving parts) are proving cost-effective for this duty in other locations.

A typical flowsheet incorporating Reichert cones and spirals is shown in Figure 5. Although cones are shown for the primary gravity concentration stage, spirals could also be used for this duty. Cones however do have the advantage of operating at higher feed densities.

Performance will naturally depend largely on the nature of the ore and the fineness of grind; but, by way of example, the results of testwork on a Reichert Mark 7A spiral treating ground gold ore are given in Table 2. The gold in the ore was associated with sulphides and the test spiral feed was cyclone underflow (to be returned to mill). The results show that 75.5 percent of the gold was recovered in a concentrate representing 2.6 percent by weight of the feed. The concentrate assayed 89.0 gms/tonne of gold compared with a feed assay of 3.04 gms/tonne, indicating an upgrade ratio of 29.3:1. Gold recovery to combined concentrate and middlings fractions was 81.7 percent.

TABLE 2
Reichert Mark 7A Spiral Concentrator
Treating Ground Gold Ore

Product	TPH	Wt. Distn	% Sols	Au g/T	UGR	Au Distn (%)
Con	0.053	2.6	37.3	89.0	29.3	75.5
Mid	0.097	4.7	61.3	4.0	1.3	6.2
Tail	1.903	92.7	36.3	0.6	0.2	18.3
Feed	2.053	100.0	37.0	3.04	1.0	100.0

Examples

At Western Mining Corporation's operations at Kambalda, gravity concentration is incorporated in the gold grinding circuit (Sceresini, 1982). The ball mill discharge is screened and the screen undersize reports to multi-stage gravity concentration which incorporates two stages of Reichert cones and two continuous strake tables operated in series. The table concentrate is stored and batched across a Wilfley table to obtain a final gravity concentrate which is amalgamated for gold extraction. Gold recoveries in the gravity circuit vary considerably, but are usually in the range 40-50 percent.

Apart from the above-stated advantages in terms of reductions of capacity requirements and costs of the CIP circuit, studies by WMC indicate that the gravity circuit has the added advantage of reducing the degree of fluctuation in the grade of ore reporting to the CIP circuit and thereby reduces the control requirements with subsequent metallurgical advantages and cost savings (Sceresini, 1983).

At the Ok Tedi Mining Limited gold/copper operation in Papua New Guinea, a five-stage gravity concentration circuit has been installed treating a portion of the milled ore. The nominally -2mm (deslimed) fraction of the mill discharge is treated on two stages of Reichert cone concentrators followed by two stages of Reichert spiral separators. The second stage spiral concentrate is retreated on a wet shaking table to produce a final gravity concentrate. In the early stages of the mine life at Ok Tedi, coarse gold recovered in the gravity concentrate is expected to amount to 20 percent of total recovery. The primary Reichert cone concentrators used in the Ok Tedi gravity concentration circuit were the first 3.5m diameter cone units in commercial operation. With a rated capacity of 300 tph (dry solids) per machine, these high capacity units offer substantial cost benefits.

TAILINGS SCAVENGING

The concept of using gravity concentration equipment for scavenging heavy minerals from tailings streams is not new. However, the development of gravity concentration equipment capable of recovering to finer sizes has added a new dimension to this application area. Palabora Mining Company in South Africa operates a gravity concentration circuit to recover very small quantities of uranothorianite and baddeleyite from its copper flotation circuit tailings. The five-stage Reichert cone circuit achieves overall recoveries of U_3O_8 and ZrO_2 of approximately 70 percent with satisfactory metallurgical performance down to very fine particle sizes (20 micron) (Van der Spuy, 1982). A similar concept using Reichert cone concentrators and/or spiral separators is applicable to the scavenging of sulphides from gold leaching circuit tailings.

Where gold is finely disseminated and locked in sulphides, incomplete gold dissolution can occur during cyanidation with a consequential reduction in gold recovery. In these circumstances, recovery of sulphides from classified leach tailings using gravity concentration, and subsequent regrind of the gravity concentrate can have a significant impact on overall gold recovery. A conceptual flowsheet for such a scavenging circuit is illustrated in Figure 6.

Reichert Mark 7A spirals have recently been proposed for installation to scavenge leach tailings at several gold operations in Western Australia (Blanks, 1983).

CONCLUSION

Gravity separation technology in the form of Reichert cone concentrators and washwaterless spiral separators now offers cost-effective systems for the recovery of gold down to finer sizes than is feasible by more conventional processes.

Reichert cones and spirals have the advantages of being relatively low cost, high capacity, light-weight and metallurgically efficient. Having no moving parts, their operating costs and energy requirements are low and manning requirements minimal.

This equipment has potential for the recovery of fine gold from alluvial deposits and in the recovery of "coarse" gold from grinding circuits and gold locked in sulphides from leach circuit tailings.

The utilisation of gravity concentration to remove coarser gold from grinding circuits can increase overall recovery and significantly reduce the capacity and costs of downstream processing requirements. Furthermore, such systems effectively reduce the quantity of gold "locked" in grinding circuits and can also facilitate the isolation of security problem areas.

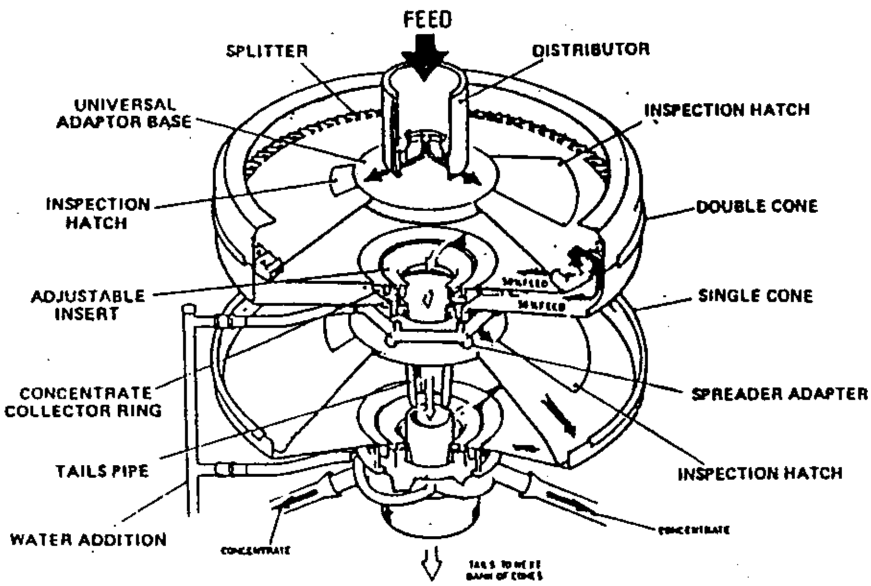
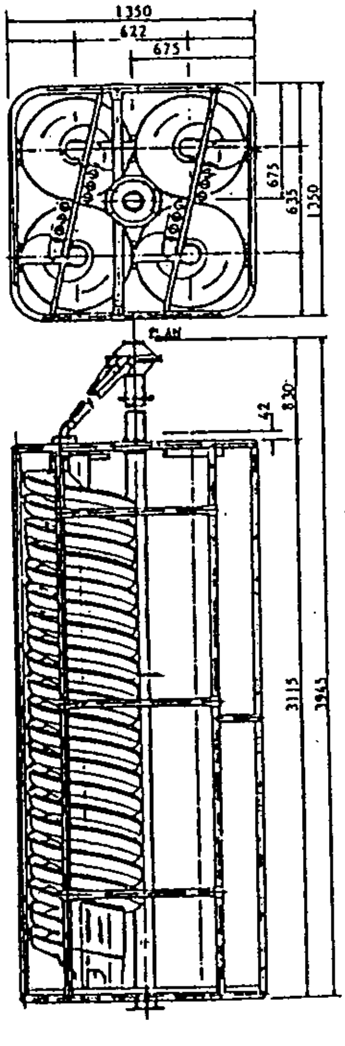
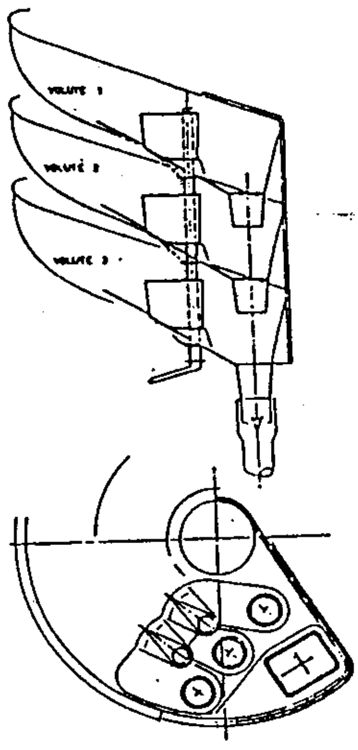


FIGURE. 1. REICHERT CONE CONCENTRATOR – SECTIONAL VIEW OF DSV STAGE.





LEFT: Plan and elevation of bank of four 3-start Mark 7A spirals. Nominal capacity of bank is 30 tph solids.

ABOVE: Enlarged view of bottom section of spiral showing ganged splitter arrangement.

FIGURE 2 : REICHERT MARK 7A SPIRAL CONCENTRATOR

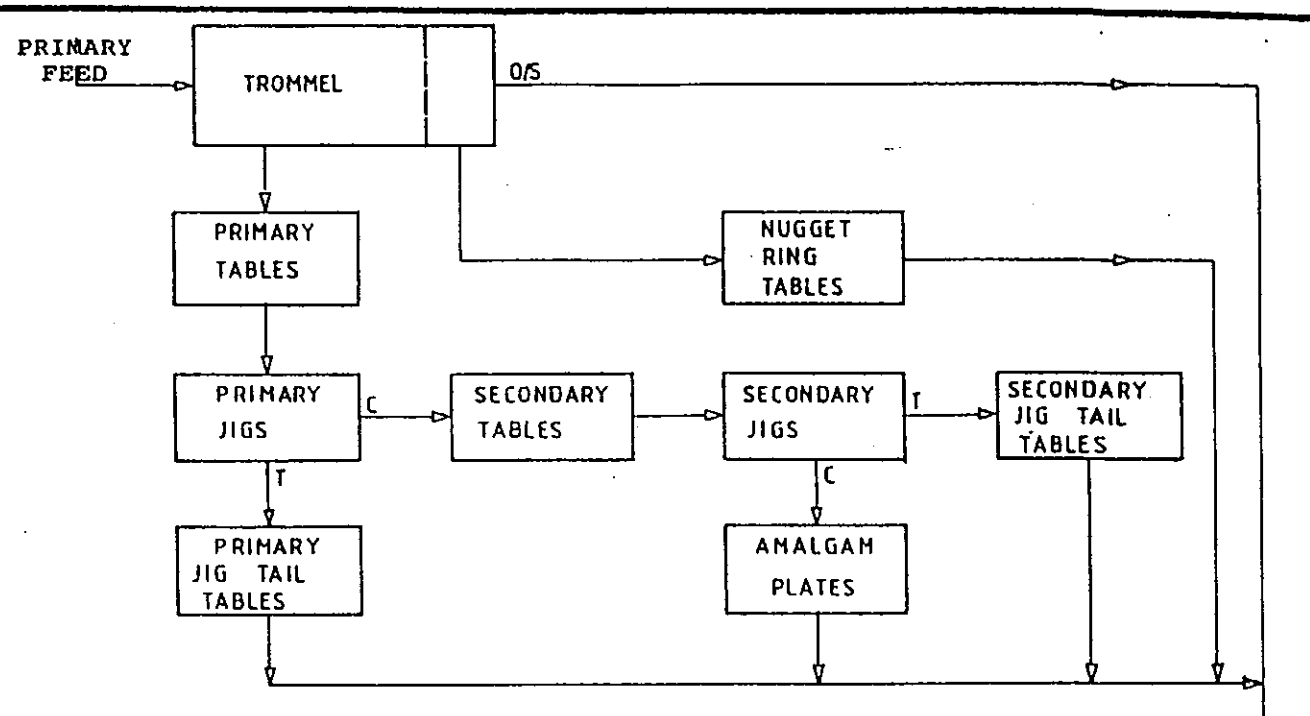


FIGURE .3. FLOWSHEET OF KANIERI GOLD DREDGE, NEW ZEALAND (CEASED OPERATION 1982)

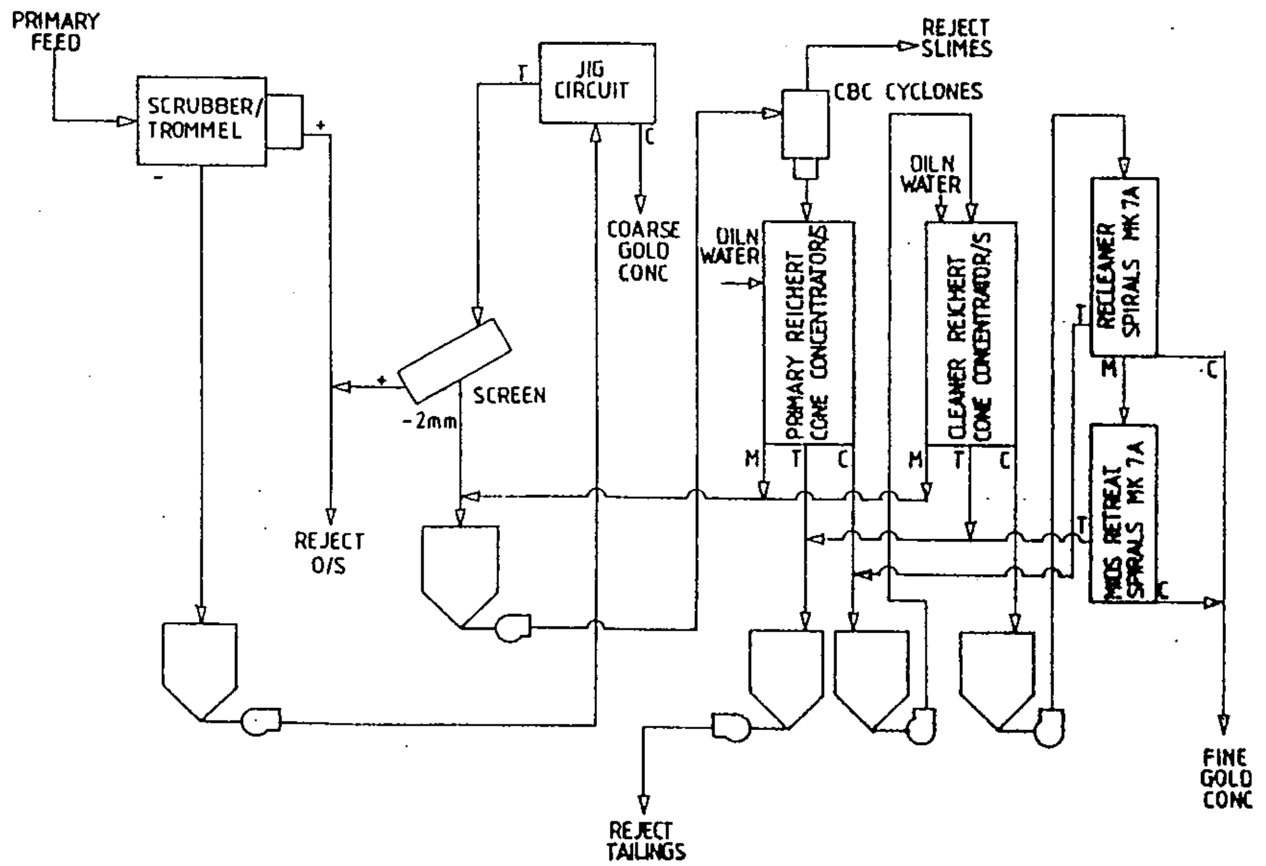


FIGURE.4. CONCEPTUAL FLOWSHEET FOR ALLUVIAL FINE GOLD RECOVERY

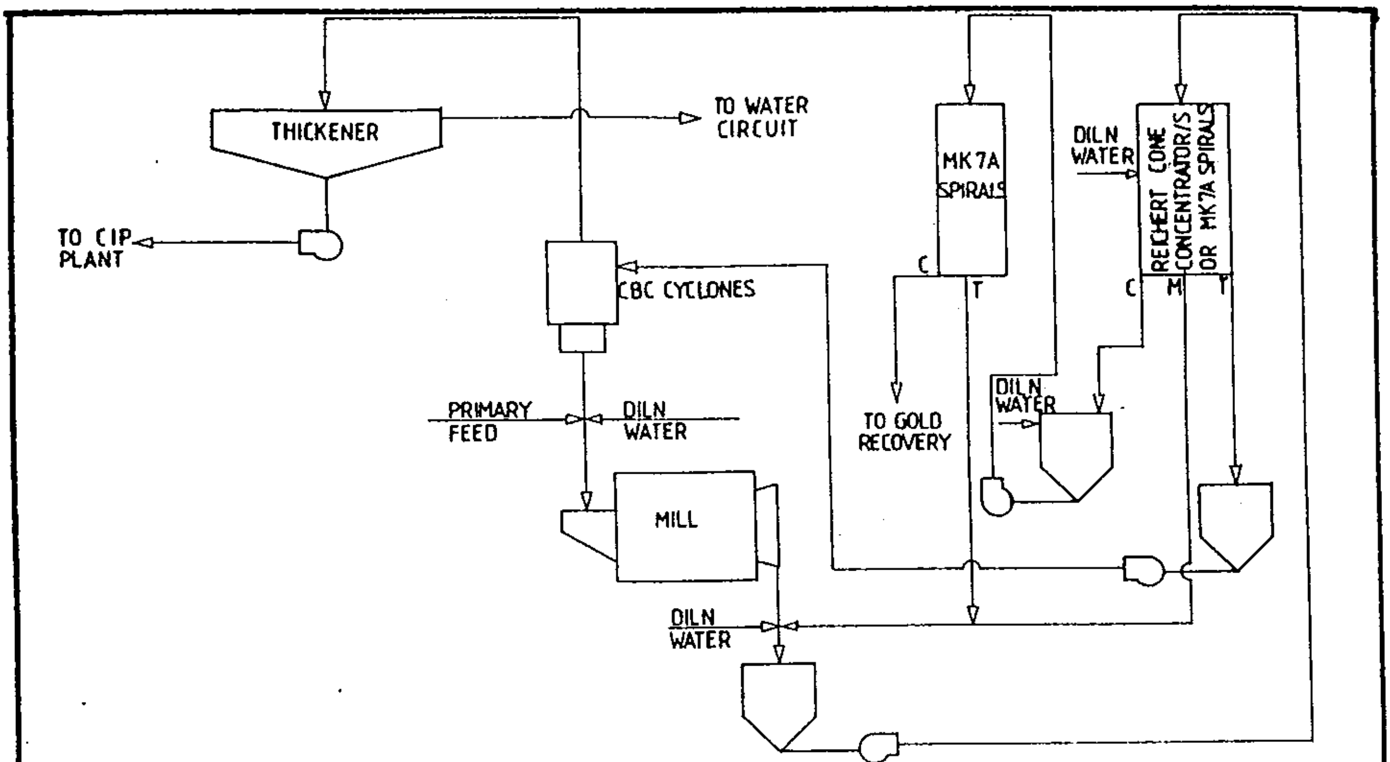


FIGURE.5. CONCEPTUAL FLOWSHEET FOR GRAVITY CONCENTRATION IN GOLD GRINDING CIRCUIT

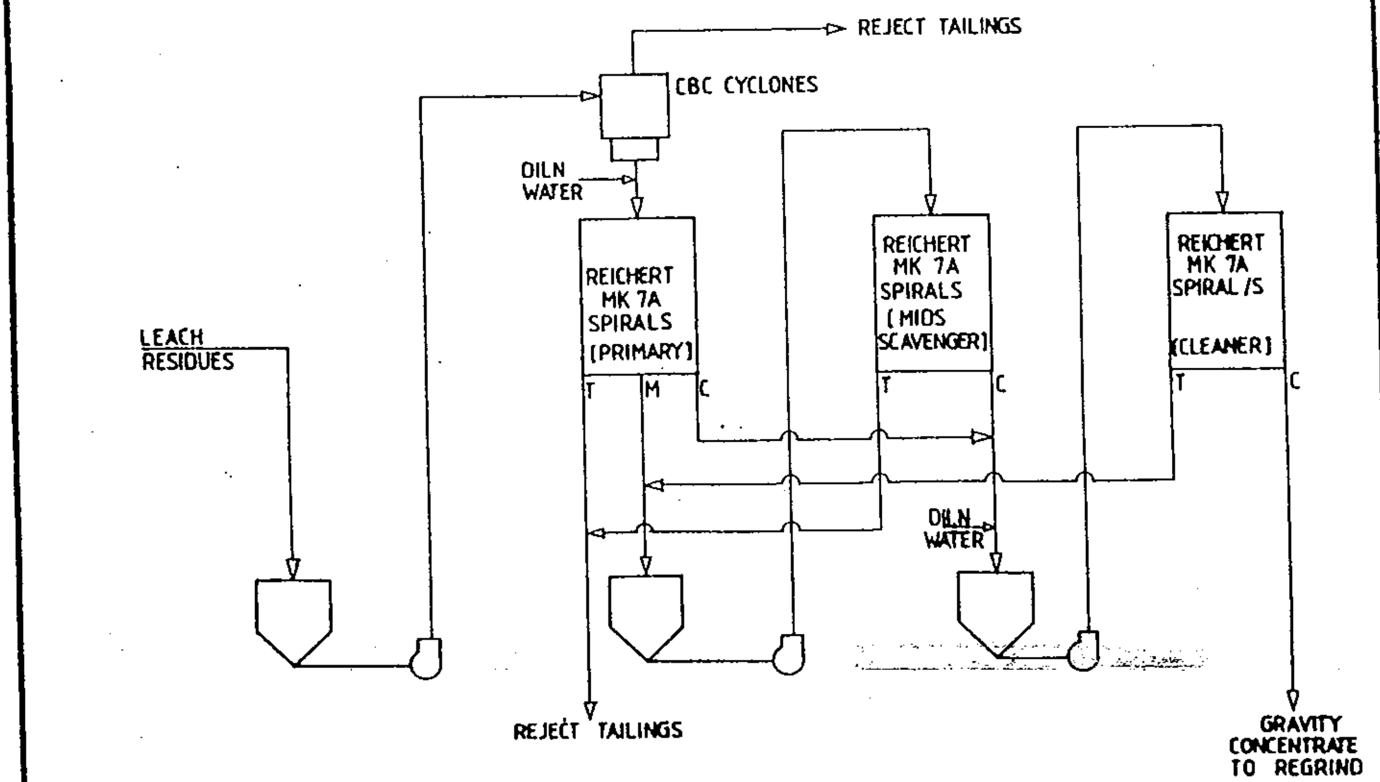


FIGURE.6. CONCEPTUAL FLOWSHEET FOR GOLD LEACHING PLANT TAILINGS SCAVENGING BY GRAVITY CONCENTRATION

ACKNOWLEDGEMENTS

The Authors with to thank the Management of Mineral Deposits Limited for permission to publish this paper.

The contribution of all personnel in the Mineral Technology Division of Mineral Deposits Limited is gratefully acknowledged.

Thanks are also expressed to the companies mentioned herein, whose permission to publish the data reported here had made this paper possible.

Any opinions expressed in this paper are those of the Authors, and do not necessarily reflect the views of Mineral Deposits Limited.

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