Some considerations in the use of gravity concentration for the recovery of gold*

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SYNOPSIS

The role of gravity concentration in the recovery of gold from typical South African gold ores is described.

The location of the concentrator in the grinding circuit is discussed, and typical capacities and operating costs are given. Some operating problems are mentioned, but the performance of concentrating equipment is not dealt with in detail since this to some extent depends on the nature of the ore.

It is concluded that the main benefits are an improved recovery of coarse gold and a reduction in soluble loss. The use of a long leaching time and a carbon-in-pulp recovery system may eliminate the need for gravity concentration, but gravity concentration is seen as an inexpensive way of improving the recovery on existing plants.

SAMEVATTING

Die rol van swaartekragkonsentrasie in die herwinning van goud uit tipiese Suid-Afrikaanse ertse word beskryf.

Die plasing van die konsentreerder in die maalkring word bespreek en tipiese vermoëns en bedryfskoste word aangegee. Sommige bedryfsprobleme word genoem, maar die werkverrigting van die konsentreertoerusting word nie in besonderhede behandel nie omdat dit in 'n sekere mate van die aard van die erts afhang.

Die gevolgtrekking is dat die vernaamste voordele beter herwinning van growwe goud en 'n vermindering van die oplosbare verlies is. Die gebruik van 'n lang loogtyd en 'n koolstof-in-pulpherwinningstelsel kan die noodsaaklikheid van swaartekragkonsentrasie uitskakel, maar swaartekragkonsentrasie word gesien as 'n goedkoop manier om die herwinning by bestaande aanlegginge te verbeter.

Introduction

It has been shown[1] that a large proportion of the gold in Witwatersrand gold ore is relatively coarse (e.g. in Vaal Reefs ore, 75 per cent of the gold is coarser than 75 μm). Relatively simple gravity-concentration circuits can therefore be used to concentrate the coarse gold for its subsequent recovery by amalgamation or other means. However, even if flotation is used in combination with gravity concentration, sufficient gold remains in the tailings of typical South African ores to warrant cyanidation of the whole ore. One must therefore justify the use of gravity concentration in its recovery of gold over and above that obtained by direct cyanidation.

It has been argued that separate treatment of a gravity concentrate constitutes a security risk, requires additional staff and equipment, and (in the case of amalgamation) is a health hazard. It is further argued that these disadvantages can be avoided if sufficient cyanidation time is allowed for the dissolution of the coarse gold particles. The benefits and costs of gravity concentration (and the subsequent processing) are discussed in this paper.

Effect on Overall Recovery

Gravity concentration has been used for many years on mines managed by the Anglo American Corporation and the Johannesburg Consolidated Investment Company (J.C.I.). Amalgamation is used to recover the gold from the gravity concentrate. Brittan and Van Vuuren[2] were able to show that the overall recovery of gold was positively correlated with the recovery of gold by gravity concentration. In view of the fact that most of the gold in the gravity concentrate is free, it is not surprising that the recovery of gold from the concentrate is about 99 per cent, while the recovery of gold from the tailings by cyanidation is only about 94 per cent. One may be tempted to believe that amalgamation is inherently a better process, and that every effort should be made to increase the quantity of gold recovery by gravity concentration. This is an over-simplification, and the additional gold may not be recovered as efficiently. For example, the pyrite in the ore usually contains gold, and this heavy mineral can be recovered by gravity concentration; however, the recovery of gold from pyrite is poor unless the pyrite has been decomposed by roasting or leaching.

Free gold particles are sometimes found in gold-plant tailings, and it is reasonable to assume that the improvements in overall recovery when gravity concentration is used as part of the recovery process are in part due to the recovery of these particles, which could be remnants of large gold particles or gold particles that are coated with iron oxide[3]. Poor dissolution of gold has also been attributed to the presence of mercury in the gold[4].

A certain proportion of dissolved gold is lost as a result of imperfect washing of the filter cake (i.e. 'soluble loss'). The gold that bypasses the cyanide circuit does not suffer this loss. The soluble loss is usually in the range 0,3 to 1,0 per cent of the gold in solution, but there is evidence to suggest that it may be significantly higher on occasions. The recovery of some of the gold prior to cyanidation would reduce the soluble loss proportionately.

The recent introduction of the carbon-in-pulp (CIP) process at some mines has effectively eliminated the soluble loss and hence part of the motivation for gravity concentration, i.e. virtually all the gold that is in solution

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is adsorbed onto the granules of activated carbon. However, the removal of some of the gold by gravity concentration could reduce the number of stages and the lock-up of gold in the CIP plant. The recovery of large or slow-leaching gold grains still remains a potential benefit of gravity concentration.

Gravity-concentration Circuits

The gold must be concentrated in the milling circuit to avoid 'over-grinding' of the gold. The gold tends to be flattened into thin platelets, which eventually appear in the classifier overflow. The concentration of gold in the hydrocyclone underflow gives an indication of the potential for gravity concentration. However, the shape factor limits the degree of concentration that can be achieved by a hydrocyclone. Concentration ratios for single-stage classification of 1,5 to 5 have been obtained[5]. This phenomenon has been used in Anglo American mines both to upgrade the feed to the gravity plant and to reduce the tonnage to be treated. Fig. 1 shows a typical three-stage milling circuit incorporating primary concentration by Johnson drums and secondary concentration using an endless belt. This configuration has become almost standard in the older Anglo American gold plants. The mass to be treated is 40 to 50 per cent of the new feed, while the gold content is enriched 5 to 50 times by the three stages of classification. Details of the operating characteristics of the Johnson drums and endless belts were published by Bath *et al.*[5] in 1973.

Single-stage run-of-mine mills are being utilized in almost all the new gold plants. In these plants, a secondary-cyclone underflow can be used to feed the primary concentrators (e.g. Johnson drums). Fig. 2 shows how two-stage classification can be used in combination with single-stage run-of-mine milling to provide a suitable feed for gravity concentration.

One could argue that the best place for the gravity concentrator is at the mill discharge or treating the underflow from the primary cyclone, thereby catching the gold before it becomes flattened and less amenable to gravity concentration. However, the flow of material to be processed (and hence the cost) increases substantially, and the device is subjected to more wear, blockages, etc. The gold locked in coarse material is not recoverable since the low concentration cannot influence the particle density. However, some unliberated gold can be recovered as a result of its association with pyrite. Two-stage classification is a very economical way of eliminating the material that is unsuitable for gravity concentration (i.e. the coarse and very fine material).

The primary concentrate is usually cleaned on an endless belt or shaking table to produce a high-grade concentrate (small mass) suitable for amalgamation. Intensive cyanidation and direct electrowinning, which were recently introduced on two Anglo American plants, is an alternative way of treating the gravity concentrate, and has eliminated the health hazards associated with amalgamation.

Selection of Equipment

The equipment must be capable of running unattended for long periods because access must be limited to avoid theft. A coating of calcium carbonate develops on the surfaces as a result of the lime used in the milling circuit,

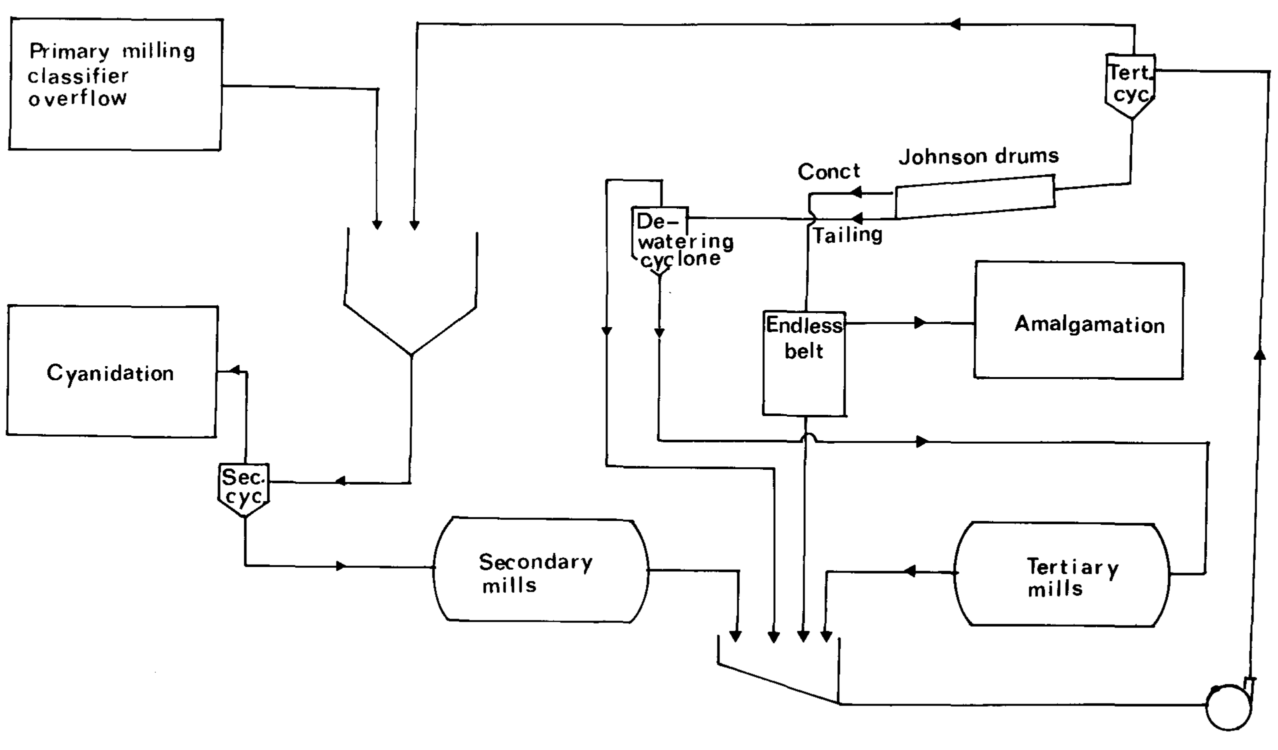

Fig. 1—Gravity concentration in a three-stage milling circuit

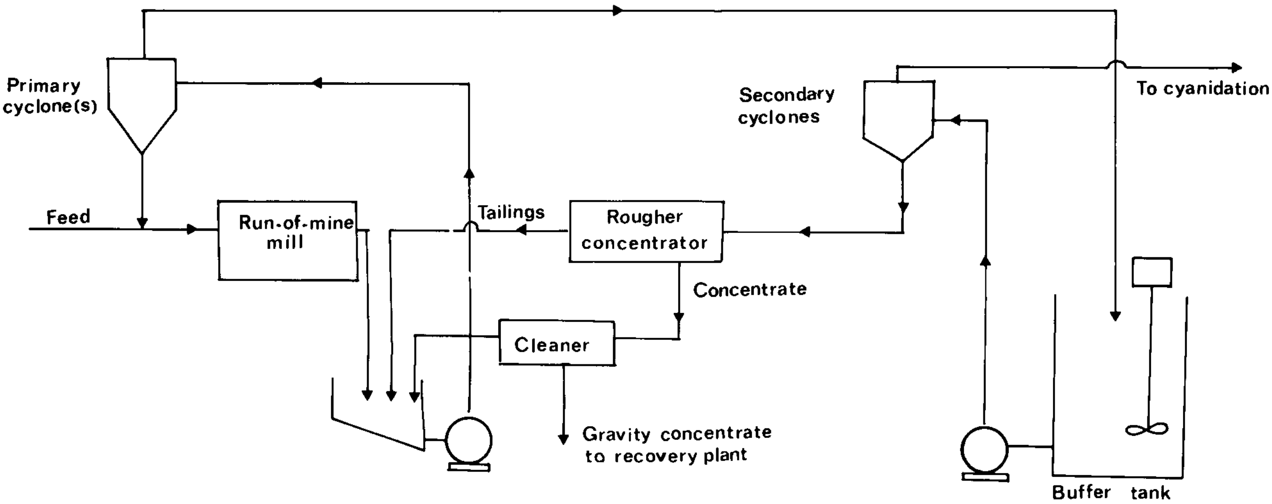

Fig. 2—Gravity concentration in association with single-stage run-of-mine milling

and regular washing with dilute hydrochloric acid is required. Mill steel also tends to accumulate, forming a hard oxidized accretion. Some mines treat the equipment with dilute acid once a week.

The Johnson drum and endless belt are continually flushed with fresh water during operation, and the surfaces are cleaned with water when there are plant stoppages. Plane tables, Reichert cones, and jigs do not have fresh water on the working surfaces and consequently are more subject to accretions of limestone and mill steel. Access for acid cleaning is difficult in the case of the Reichert cone, and the mechanism for adjusting the cutter can become jammed with limestone relatively quickly. A Reichert cone installation at the President Steyn Gold Mine was replaced by Johnson drums because of the operating problems mentioned.

The Johnson drum recovers a relatively constant mass of concentrate[6], which is almost independent of the feed rate. This is a useful property as upsets in the milling circuit do not cause problems in the gravity circuit. The cleaner (e.g. endless belt) is provided with a relatively constant feed. A significant drop in the feed rate to a plane table or Reichert cone reduces the velocity of the pulp, which can result in a larger mass of rougher concentrate.

Yuba–Richards duplex jigs were installed as original equipment at the Western Areas Gold Mine North Plant in the early 1960s with the object of producing a moderate tonnage of pyrite concentrate at a relatively low cost. At that time it was found possible to effect a 50 per cent recovery of pyrite and a 35 per cent recovery of gold from jigs operating both in the open-circuit rod-milling and closed-circuit pebble-milling grinding sections of the plant. Jig rougher concentrate from this circuit, amounting to about 5 per cent of the new feed tonnage, was upgraded by means of cleaner jigs, riffle belts, and James tables before final recovery of the gold by amalgamation.

An increase in the demand for pyrite led to the installation of a more efficient pyrite flotation circuit, the jigs continuing to be used only as gravity gold concentrators. In this mode they were found to be relatively labour- and maintenance-intensive, the operating costs in 1972 being about 5 cents per ton treated. An added disadvantage of the jigs at that time was the quantity of water required for the jig circuit. In the period June 1972 to June 1973, the jigs at North Plant were replaced by Johnson concentrators.

At the present time, both the North and South plants at Western Areas have gravity circuits equipped with Johnson concentrators. The recovery of gold in these circuits is 35 per cent and 38 per cent respectively.

Costs

An in-house evaluation of gravity concentration used with run-of-mine milling, which was conducted in 1981, showed that the capital cost of Johnson drums and endless belts is about 36 cents per annual ton of ore. The capital cost of the associated intensive cyanidation facility is about 55 cents per annual ton, giving a total of 91 cents per annual ton of ore.

The operating cost for intensive cyanidation is uncertain at this stage. However, the total operating costs for concentration and amalgamation are about 4 cents per ton of ore, of which 1 cent is for labour and 1,6 cents for additional assays and services.

These costs should be compared with that of additional cyanidation time. The capital cost for an additional 18 hours in air-agitated pachucas is about 40 cents per annual ton, and the operating cost is about 6 cents per ton. The equivalent costs for mechanically agitated tanks are about 20 cents per annual ton and 1,8 cents respectively.

The justification for installing a gravity-concentration circuit must be based on the additional recovery of gold, as mentioned in the Introduction. The sources of potential gold loss have been identified, i.e. coarse gold, which leaches slowly, and soluble loss, which can be reduced by the decreasing amount of gold entering the cyanidation tanks. The soluble loss depends upon the state of the filters and the amount of ultra-fine material. The recovery of 50 per cent of the gold by gravity concentration can reduce the soluble loss from say 0,6 to 0,3 per cent. The value of the saving is obviously a function of the head grade, and gravity concentration is usually considered for high-grade circuits. An improvement in recovery of 0,3 per cent for an ore containing 8 g/t is worth 24 cents per ton (for a gold price of R320 per ounce).

Viewed in isolation, the costs indicate that the provision of additional leaching time is a more economical way of ensuring the recovery of coarse gold. However, the simultaneous reduction in soluble loss can provide a strong case for gravity concentration.

Recovery of Gold from Concentrates

The recovery of gold from concentrates by amalgamation is an old, established process, which need not be discussed here. Some of the gold can be recovered into a flotation concentrate for direct smelting, but the tailings must still be processed.

Intensive cyanidation and electrowinning were developed by the Anglo American group in recent years as an alternative to amalgamation. This process is being considered for both old and new mines. The design parameters are not fully optimized at this time, but the following procedure has been followed on a production plant for about two years.

(a) The concentrate is vigorously mixed in a 2 per cent sodium cyanide solution using a modified flotation cell mechanism, which also ensures efficient aeration. The injection of oxygen or hydrogen peroxide increases the rate of leaching by up to five times, but the use of air appears to be more economical. The leaching time is usually about 20 hours.

(b) Care has to be taken that the recovery of gold is not limited by its solubility. The concentration of gold in the concentrate can be high on occasions or the temperature low, or other ions in solution may limit the solubility.

(c) The residue is filtered and washed. It can either be returned to the milling circuit (which results in a build-up of mill steel) or it can be roasted together with other pyrite arisings to liberate some of the residual gold.

(d) The pregnant liquor is passed through electrowinning cells (packed with steel wool) for the recovery of metallic gold, and the residual solution joins the normal cyanidation circuit.

Further Points

The soluble loss should be determined by the addition of activated-carbon granules to the slurry after leaching. The residue obtained by this method is often lower in gold than that obtained by washing, since the gold that is adsorbed onto gangue minerals (or precipitates) is transferred to the activated carbon. The soluble loss will be reduced in proportion to the amount of gold recovered by gravity concentration.

Gravity concentration will recover significant quantities of pyrite, uraninite, and other heavy minerals found in the matrix. The cleaner (endless-belt) tailings should be subjected to fine grinding (e.g. in the Anglo American three-stage grinding system) or reverse leaching to improve the liberation of the refractory gold. The endless-belt tailings in the low-grade circuit at the Western Deep Levels Gold Mine are pumped to the high-grade circuit, which is subjected to acid leaching.

The residence time of the gold in the thickener, leaching pachucas, and recovery circuit may be 3 to 4 days. The gold recovered by concentration spends a substantially shorter time in the system, and consequently the gold inventory is reduced.

Osmiridium can be recovered as a byproduct of the system using gravity concentration and intensive cyanidation.

It is unlikely that gravity concentration will recover kerogen (thucholite). Flotation of the whole ore is required for the recovery of this mineral, which usually carries high values of gold and uranium. The recovery of kerogen by flotation appears to be far from satisfactory, and ways of improving it should be investigated.

Conclusions

The use of gravity concentration and amalgamation or intensive cyanidation can improve the overall recovery of gold from Witwatersrand ores by

(i) reducing the soluble loss and gold adsorption on gangue minerals,

(ii) recovering large or slow-leaching gold particles that would otherwise be incompletely leached, and

(iii) providing an opportunity to subject refractory gold (e.g. in pyrite or uraninite) to alternative processes.

The use of a combination of a long leaching time, carbon-in-pulp recovery of gold, and pyrite flotation may make it unnecessary to use gravity concentration. However, should an existing plant not have these options, gravity concentration provides an inexpensive way of increasing the overall recovery. In view of the fact that the overall recovery may be increased by less than 0,5 per cent, careful experimental work is required to establish the benefits of various process options. The reasons must be found by inductive logic based on the results of mineralogical studies.

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