Photometric sorting of ore on a South African gold mine

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SYNOPSIS

This paper concerns the development and application of a high-throughput, multi-stream photometric sorting machine developed for the South African gold mines. It is now believed that this sorter and its progeny may be found suitable for a large proportion of all possible sorting applications. A laser-light source and sensitive photomultiplier are employed in a scanning system to detect light reflected from the surfaces of rocks passing through the sorting zone. Electronic circuitry then analyses the photomultiplier signal, which represents the varying intensity of the reflected light, and produces control signals to actuate the appropriate valves of an array of air-blast rejection devices to remove from the feed certain particles selected by the analysing process. Typical throughput per machine ranges from 50 t/h for a minus 60mm plus 30mm feed to 200 t/h for minus 150mm plus 70mm material.

SAMEVATTING

Hierdie refera handel oor die ontwikkeling en gebruik van 'n fotometriese veelstroomsorteermasjien met 'n hoë deuervoer wat vir die Suid-Afrikaanse goudmyne ontwikkel is. Daar word nou gerekent dat hierdie sorteerder en sy nageplaag kan blyklik geskik is om wat vir 'n groot deel van alle moontlike sorgtiregiskaart was om op te spoor wat weerkaats word van die oppervlak van rotse wat deur die sorgtirezone gaan. Elektroniese baanwerk ontled en dan die fotoversienigydiger se sein wat wisselende intensiteit van die weerkaatste lig verteengroott en gee kontroleinsiste om die goepe kleppe van 'n reeks lugspertoestelle in werking te stel wat sekere deeltjies wat deur die ontledingsproses gekies is, uit die toevoer te verwyder. Die tiiese deuervoer per masjien wissel van 50 t/h vir 'n toevoer van minus 60 mm plus 30 mm tot 200 t/h vir materiaal van minus 150 mm plus 70 mm.

INTRODUCTION

Early in 1966, agreement was reached between Gold Fields of South Africa Limited and Ore Sorters of the RTZ group, with member companies in Canada and South Africa, whereby research would be undertaken by Ore Sorters in Canada for the purpose of developing a sorter using a photometric technique. Ore Sorters meanwhile had been investigating many other techniques. Preliminary work in 1966 produced results promising enough to gain approval for the fabrication of a full-size prototype sorter. This prototype was built and designated the Model 12. It was used from early 1969 until mid-1973 on one of the mines of the Gold Fields Group in South Africa as a pilot unit for the evaluation of the sortability of various gold and other ores. Early in 1972, an order was secured from the Doornfontein Gold Mining Company Limited, another of the Gold Fields' mines, for the first commercial sorter. This machine, the Model 13, was constructed according to the principles used in the Model 12, but was redesigned throughout to incorporate certain improvements prompted by experience gained from testwork on the Model 12. The Model 13 has been operating there since it was placed in service in November 1972.

Hand-sorting of ore, based on human visual examination of the ore, is by no means new. This method of upgrading mine output is a practice still followed today, even in certain high-tonnage situations. More recent times have seen the successful installation of mechanical sorters capable of performing sophisticated analyses of ore particles at rates of throughput consistent with today's mine outputs.

Generally, sorting will be undertaken for one or more of the following purposes:

(i) To separate mine output ore into two fractions, one containing valuable minerals and the other essentially barren.

(ii) To select from the mine output ore, at an early stage, certain high-grade pieces which, if they are allowed to remain with mine output during further processing, will become less valuable. For example, particles containing asbestos in long fibres could be preserved from the damage inflicted by further crushing in association with a hard waste rock.

(iii) To remove from mine output particles containing contaminating material that will make succeeding stages of the mineral extracting process inefficient or expensive. For example, a uranium-bearing ore diluted by dolomite will consume excessive quantities of acid during leaching.

(iv) To select 'best quality' pieces from mine output in a situation where different grades of the same material are salable at different prices. In some cases both products may be salable. Mechanical ore sorting is practical for particle ranging in size from approximately minus 150mm to plus 6mm. But the particles sorted by a particular machine will normally fall within a lesser range, for example minus 40mm to plus 15mm. If an ore is to be sorted by a device dependent on electronic discrimination, the valuable substance, or the particular property which is of value, must be contained more or less exclusively in certain of the...
pieces and must not be evidenced in significant degree by the remaining pieces. The valuable pieces must be distinguishable from the non-valueable pieces by virtue of some identifying and identifiable characteristic.

Most of the gold ores of the Witwatersrand mines have these latter characteristics, as evidenced by the fact that most mines do a hand-sorting operation for the removal of waste rock from the ore coming out of the mine. This manual operation is dependent on a person being trained to observe the characteristic appearance of the valuable reef or the virtually barren waste in the ore. Since that person has to use his eyesight for this purpose, it was concluded that an optical instrument should be able to do the same operation. This led to the production of the Photometric Sorter. (It should be noted that the valuable portion of Witwatersrand ore is normally referred to as reef.)

Machine throughput is a variable depending on the size of feed particles, the sorting accuracy required, and the difficulty of distinguishing valuable from non-valueable pieces. Typical throughput figures for various ranges of feed material as determined by extensive testwork with the Model 12 prototype are as follows:

<table>
<thead>
<tr>
<th>Feed Material (mm)</th>
<th>Throughput (t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-150 +70</td>
<td>200</td>
</tr>
<tr>
<td>-100 +50</td>
<td>130</td>
</tr>
<tr>
<td>-80 +40</td>
<td>90</td>
</tr>
<tr>
<td>-60 +30</td>
<td>60 (Model 13)</td>
</tr>
<tr>
<td>-40 +20</td>
<td>30</td>
</tr>
</tbody>
</table>

The Photometric Sorter separates rocks into two categories according to light-reflectance properties. The 'accept' category in the case of the Doornfontein machine includes those rocks having white or grey quartz pebbles in a darker surrounding matrix, which have to be recognized by the machine as reef, while the 'reject' rocks are either quartzite ranging from light green through olive green to nearly black or tuff, which is black, and has to be recognized as not being reef. These distinguishing optical characteristics are typical of the gold ores occurring on the Witwatersrand in South Africa. This sorting is based on the knowledge that gold occurs mainly in the rocks that are recognized in the accept category. The sorter is calibrated for the type of ore feed, and may have to be recalibrated should the characteristics of the feed change, as happens when mining moves to new areas and reefs of a mine.

The machine described in this paper, the Model 13, installed at the property of the Doornfontein Gold Mining Company Limited on the goldfields of the Witwatersrand in South Africa, has been designed to handle rocks ranging in size from...
30mm minimum to 80mm maximum, at rates of 45 to 65 tonnes per hour depending on particle size. The machine has an effective sorting width of 810 mm.

The sorting function proceeds as follows. Rocks are fed continuously to a conveyor belt and are randomly distributed on it so that no two rocks touch each other. The conveyor belt carrying the rocks passes through a scanning zone, where information for each particle concerning its size, light-reflectance pattern, and location on the belt is gathered. At the instant each rock leaves the scanning zone, the control makes a decision to accept or reject based on the size and light-reflectance pattern of that rock. Then, using the size and location information, an air blast is applied by solenoid-operated valves to 'accepted' rocks as they fall from the end of the conveyor in order to alter their natural free-fall trajectory and thereby separate them from the remainder of the stream.

DESCRIPTION OF THE MODEL 13 PHOTOMETRIC SORTER

There are four basic functions to be carried out in the Photometric Sorter: presentation of the particles, sensing of position, size, and optical properties, signal processing, and separation of accept and reject material.

The mechanical layout of the unit, which is described below, is shown schematically in Fig. 1, and Plates I to V show various views of parts of the machine.

Presentation

Proper feeding of ore to the sorter is critical for optimum metallurgical results. Overfeeding causes excessive crowding of the particles and doubling up in the sensing-separation zone, adversely affecting separation efficiency. Underfeeding does not appreciably increase machine efficiency but does decrease the capacity of the machine.

Clean, washed feed should be correctly sized to the specifications for which the machine has been designed. The presence of excessive undersize in the sorter feed decreases the capacity and efficiency of the machine.

The two main requirements in the feeding of ore to the sorter, namely,

(i) controlled feed rate, and
(ii) one-layer deep presentation to the slide plate,
are obtained by the use of a tandem vibrating feeder assembly.

Tandem vibrating feeders

The primary vibrating feeder draws the sized feed from a surge hopper at a controlled rate and delivers it onto the secondary feeder. It is fitted with an electronic amplitude control in order to provide a constant, closely regulated feed rate.

The secondary feeder removes excess water, spreads the ore out into a single layer, and alters the ore flow from a 20° inclination to a 45° inclination by means of a curved discharge lip.

Slide plate

The slide plate imparts acceleration to the particles of ore, thus increasing their relative spacing. The bottom of the plate is curved to provide a direction transition from 45° downwards to the horizon.
horizontal plane of the belt surface. Ideally, particle speed at the bottom of the slide plate and belt speed should be closely matched to have a minimum of movement of the particles relative to the belt surface as they land on the belt. Any movement on the belt tends to lead to touching and inefficient sorter operation.

Water sprays

Water sprays are fitted over the lower feeder to wet the rocks upstream of the sorting belt, in order to enhance differences in their light-reflectance properties, as well as to remove slime and a fair quantity of the fines created in the handling of the feed between the time it leaves the main mine sorting plant, as described later, and becomes sorter feed.

Sorting belt

This is a white PVC three-ply endless belt driven from the head pulley and with a crowned tail pulley. It is supported at 100m intervals by idlers to maintain it on a constant plane. It serves to present the rocks to the scanning zone in a stable manner, at constant speed, and against a uniformly light background. The belt is kept clean by means of a mechanically driven scrubber brush.

Sorter dimensions

The approximate dimensions of the machine, including vibrating feeders, scanning cabinet, and blast enclosure, are as follows:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall height</td>
<td>4.5 m</td>
</tr>
<tr>
<td>Width</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Length</td>
<td>8.0 m</td>
</tr>
<tr>
<td>Width over frame of sorting belt</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Width of sorting zone</td>
<td>810 mm</td>
</tr>
</tbody>
</table>

Sensing

The scanning system, which is shown schematically in Fig. 2, comprises a helium neon laser light source, an octagonal mirror drum, and a photomultiplier assembly in which is fitted a lens system, field stop, polarizing filter, and red-light sensitive photomultiplier tube. The laser emits an intense, virtually non-diverging beam of polarized light. The light beam from the laser is intercepted and directed towards the surface of the conveyor belt by one of the eight mirrors of the mirror drum rotating at high speed, thereby effecting a scanning action across the width of the belt. The photomultiplier assembly receives some of the laser light returned from the surfaces of the conveyor or rock particles travelling on it via reflection from a second mirror of the mirror drum, i.e., the photomultiplier also scans the conveyor surface. The laser and photomultiplier are aligned with the mirror drum in such a way that the 3mm-diameter laser beam remains approximately central within the 25 mm circular field of view of the photomultiplier on the conveyor, so that the two beams scan across the conveyor in synchronism. By passing the light received by the photomultiplier assembly through a polarizing filter oriented to eliminate light reflected from spectacular surfaces, the signal produced by the photomultiplier is made representative of the true reflectance of the objects viewed, i.e., the intense specular reflections that may be produced by moisture on the reflecting surfaces are ignored.

The scanning cabinet is continually flushed with filtered air to keep the various optical surfaces of the scanning system clean and thereby maintain peak sorting performance. Typically, this scanning system
can detect a spot as small as 1mm in diameter if there is sufficient difference in reflectance between the spot and the background. In the Model 13, the scanning rate is essentially 400 scans per second, and the conveyor belt speed is approximately 2000 mm/s, which results in a scan-to-scan interval of 5mm. A 30mm piece of rock would therefore be 'seen' five or six times.

**Signal Processing**

The video signal from the photomultiplier, together with certain timing signals also derived from the scanning system and another timing signal picking up the conveyor-belt speed, is applied to the electronics unit. The video signal is amplified and stabilized so that it will be unaffected by changes in the operating environment such as temperature, power-supply voltage, and laser-light power output.

Comparison of the instantaneous value of the video signal to certain preset reference voltages is performed to determine the following:

1. the presence of rocks in the scan, and
2. such quantities as
   a. those portions of rock that are darker than a certain reference level, or
   b. the occurrence of a change in the signal, which represents the transition of the scan from one point on a rock's surface lighter than a first reference level to another point darker than a second reference level. (It is typical of Witwatersrand ore that gold occurs around light pebbles in a dark matrix.)

The sorter can be programmed to evaluate individual particles on the basis of, for example,

a. the percentage of the total observed surface area that is darker than some predetermined reference level, or
b. the average number of transitions from light to dark areas or from dark to light areas per unit of surface area, or

c. combinations of these and similar derived parameters.

Since the scanning action is synchronized with the timing of the electronics, the size and position of each rock encountered by the scan can be deduced.

There are a number of Analysing Modules, each containing circuitry for the accumulation and analysis of the data related to the surface character of the rocks, and further circuitry to retain data related to size and position. As each rock first appears in the scan, it is assigned to one of the Analysing Modules, and, on each successive scan in which the rock is 'seen', the additional information acquired is similarly directed to that Module.

At the first scan in which a particular rock is no longer found to be present, i.e., when the rock has passed completely through the scan, the Module is requested to render a decision on whether the rock is reef or waste, i.e., whether it is to be accepted or not. If the rock is to be air-blasted to remove it from the remainder of the stream, i.e., if it is accepted, appropriate information is transferred from the Analysing Module via delay registers to those air-blast valves whose nozzle positions correspond to the size and position of the rock at the time of air discharge. Either reef or waste can be blasted, depending on the relative preponderance of the two constituents. At Doornfontein, reef is blasted.

**Separation**

**Blast manifold**

The channel blast slots (blast manifold) are located downstream from the scanning line and below the head pulley of the sorting belt. Particles pass in free fall over the blast manifold.

Correct adjustment of the blast manifold is critical for achieving the co-ordination of the full air blast with the arrival of the accepted particle in front of the blast slot. Improper timing of these events will cause 'premature' or 'late' blasting. The time at which a valve opens and the time for which it remains open are controlled by the electronic circuitry.
Blast valve design

The blast valve unit is composed of two elements, consisting of a pilot valve and the main valve, each operating on separate, independent air supplies. Pilot air pressure is maintained at a differential that is 50 to 100 kPa higher than the main air supply to assure positive valve functioning. The pilot valve, a three-way normally open Valvair solenoid type, controls the release of the main air diversion blast.

Blast valve operation

On commencement of the blast command signal, the chain of events occurring in the channel pneumatic circuit is as follows:

1. The command signal energizes the solenoid coil of the pilot valve, drawing the spring-loaded plunger up against the top seat and shutting off the pilot air;
2. As the plunger rises, the pilot valve ports to atmosphere, relieving the differential pressure against the crown of the main-valve poppet to maintain the main valve in a normally closed position;
3. As the pilot pressure on the main-valve poppet drops rapidly below that of the main air supply, the poppet slams open against a rebound plate, venting the full main air flow to the blast slot;
4. On cessation of the command signal, the solenoid coil de-energizes, releasing the pilot plunger; under pilot air pressure, assisted by the compressed spring, it quickly returns to the normally open position against the bottom seat;
5. As the poppet drops, it closes the port to atmosphere and re-admits the pilot air to the crown of the main-valve poppet, returning it to the normally closed position.

Blast timing

Improper blast timing, requiring correction if optimum metallurgical performance is to be maintained, can occur only if the blast manifold has been moved or one of the electronic circuits has become faulty. In the case of the latter, the timing error would generally be very obvious—so much so that the blast may entirely miss the particle for which it was intended.

Splitter plate

An adjustable plate is provided in the discharge product area of the sorter installation. Product-disposal conveyor belts on both sides (and below) the splitter plate transport the two fractions to their respective destinations.

OPERATION OF THE MODEL 13 SORTER

The first installation of a Model 13 Sorter has been in operation at the Doornfontein Mine since November 1972. Details of its operation and costs are set out in this section.

Operation

The following are the operating requirements for the Model 13 Photometric Sorter.

Compressed air

The amount of compressed air required is dependent on the size of the rock being sorted, but, in a typical case, the figure would be about 35 m³ of air per tonne blasted. At a feed rate of 50 t/h, and with 28 per cent being accepted, a representative air requirement would therefore be about 500 m³/h, but capacity requirements should be double this to compensate for short-term fluctuations in feed rate or percentage accept.

Electricity

The power requirement of the Sorter, including the vibrating feeders but excluding transport to the plant and any product-disposal systems, is 15 kW.

Water

Clean water to the wetting sprays over the secondary feeder is required at a rate of 15 l/s.

Personnel

An operator should be available to oversee the functioning of the Sorter, but, since it is fully automated, this duty can be performed on a part-time basis by an operator normally engaged elsewhere, i.e., at crushers or conveyor belts nearby.

Maintenance

In the year 1973 the value of the spares used in the maintenance of the Sorter amounted to approximately R9000. Of this, nearly half was for white sorter belts, which required replacement. Six belts were used during the year, but strict attention to operating procedures has now resulted in much increased belt life.

The blast manifold was another item subject to wear, but the maintenance costs have been reduced considerably by:

(i) efficient removal of water containing fine 'sand' on the secondary feeder, since this acts as a scouring agent when it flows into, and is then blown out of, the blast manifold;
(ii) use of replaceable blast slot inserts fabricated from high-density polyethylene or polyurethane.

The valves themselves have been remarkable in performance, requiring virtually no attention. Each valve blasts at least 40 million times during a year of operation.

Four laser tubes failed, but each of these was replaced under guarantee.

The mirror drum was replaced after a year's operation owing to scratches caused by failure to observe careful handling in cleaning.

Electronic faults occurred on five printed circuit boards on three occasions and accounted for only a small proportion of the maintenance costs.

With the operating experience gained during this first year, the amount and cost of maintenance spares have been reduced to a very low level. The costs for the first year are summarized in Tables I and II.

TABLE I

**SUMMARY OF OPERATING COSTS—JANUARY TO DECEMBER, 1973**

(MODEL 13 SORTER—DOORNFONTEIN GOLD MINE)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit value of feed</th>
<th>Unit value of energy</th>
<th>Unit value of water</th>
<th>Rate of water</th>
<th>Rate of feed</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air</td>
<td>0,05 c/m³</td>
<td>0,5</td>
<td>0,2</td>
<td>4 c/l</td>
<td>500 c/m³</td>
<td>14,4</td>
</tr>
<tr>
<td>Electricity</td>
<td>0,47 c/kWh</td>
<td>0,2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>4 c/l</td>
<td>0,1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator</td>
<td>300 c/h</td>
<td>3,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>4,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>0,6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*These figures are expected to drop by about 7 c/t when the plant is run as a normal operation, i.e., when there is no testwork.
TABLE II
CONSUMPTION OF SPARES — JANUARY TO DECEMBER, 1973
(MODEL 13 SORTER—DOORNFONTEIN GOLD MINE)

<table>
<thead>
<tr>
<th>Item</th>
<th>Approximate value (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White sorter belts</td>
<td>4 000</td>
</tr>
<tr>
<td>Blast manifolds</td>
<td>1 200</td>
</tr>
<tr>
<td>Other mechanicals</td>
<td>2 400</td>
</tr>
<tr>
<td>Optics</td>
<td>1 100</td>
</tr>
<tr>
<td>Electronics</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>R 9 000</strong></td>
</tr>
</tbody>
</table>

Plant Availability

Virtually all maintenance was performed on a planned schedule without interruption to production, requiring the attention of one artisan on one eight-hour shift per week. Plant availability of the sorter for the entire operating period amounted to 97 per cent. Another 4 per cent of time was lost due to factors outside the sorter, such as electric power supply, compressed air, and modifications to the plant that affected the feed arrangements.

Application and Metallurgical Results

The Doornfontein installation is a scavenger operation. As the reliability of the sorter under plant operating conditions over long periods had to be proved, the mine management decided to install the initial sorter on a low-grade current reject resulting from a manual reef-picking operation. The sorter was so installed that any failure would not affect normal mill operations. Initially, this proved to be a wise decision, but soon the sorter was shown to be reliable and to operate for extensive periods with little down-time.

The sorter was installed to receive a minus 50mm plus 32mm feed, a size at which manual reef picking starts to become inefficient.

The ore from the mine contains the ‘valuable’ Carbon Leader Reef, a feebly developed though persistent reef generally having a small pebble band, often only 5cm to 8cm in width with the pebbles usually about 2cm in diameter. The lower layer of pebble is often partly embedded in carbon-rich material, where the gold is almost exclusively found. Sometimes the pebble is entirely absent and only a pencil-line seam of carbon occurs.

The overlying rock layer immediately above the Carbon Leader and below the main Green Bar country rock is 2 to 4 m thick and is a dense, fine-grained, glossy, light-grey to almost black quartzite, often with pyrite stringers. The Green Bar is a chloritic shale. The immediate footwall of the Carbon Leader is a medium-to-coarse-grained grey to khaki quartzite. The run-of-mine feed to the milling plant, because of the minimum stope width necessary for personnel to work in, contains quantities of all these country rocks, in addition to the gold-bearing reef (i.e., the valuable portion of the ore), resulting in a fairly wide range of rocks that have to be recognized as waste, or rather as not being reef.

The main crushing plant run-of-mine feed material is reduced to minus 150mm by jaw breakers and is screened on 38mm washing screens. The screen undersize (minus 38mm), which contains a large percentage of the gold, after further crushing becomes rod-mill feed. Inevitably, a large percentage of this material consists of waste rock and will be well worth sorting when a machine for these lower size ranges is brought into operation. The oversize is subjected to a manual reef-picking operation; the picked reef with a gold value of some 14 g/t is then used as the grinding medium in the tube-milling operations. Prior to the installation of the Photometric Sorter, the balance was sent to a storage dump.

As a result of the reef-picking operation described above, some 31 per cent of the run-of-mine material was being sent to the storage dump, and the mill feed was upgraded from about 10 g/t to some 14 g/t; the tonnage to be milled was reduced from some 169 000 to 116 000 t a month. The reject material sent to the storage dump (about 53 000 t per month) at 1.7 g/t of gold contained some 5 per cent of the gold in the run-of-mine material. When the capital cost of a milling plant and operating costs were taken into account, it was uneconomic to treat the material at the $35 per ounce gold price prevailing during the sixties. It was therefore regarded as material that would be treated at a later stage when the economic picture changed and/or mill capacity became available.

At least one of these events was predicted for the early seventies, and indications were that, if this reject material were upgraded, the available mill capacity resulting from any small reduction in mining operations could be filled with an economic material. Upgrading could be achieved by screening followed by electronic sorting.

Installation of the sorter at Doornfontein was completed in November 1972, and the first three months of trial operation necessitated various adjustments and changes in this first commercial plant. The figures quoted in this paper are the results for the next year of operations. As mentioned below, various factors outside the sorter resulted in less than peak performance, but the results have nevertheless been most encouraging. The additional gold recovered more than paid for the installation in the first six months.

The sorter feed consists of a screened fraction of the discard material from the existing reef-picking plant in the minus 50mm plus 32mm range. Of this original discard tonnage, 32 per cent, containing 45 per cent of the gold discarded and running at 2.5 g/t, falls into this fraction, which is now sent to the sorter. (The plus 50mm material is subjected to a further hand-sorting operation, which recovers a further small but high-grade tonnage of ore, and the minus 32mm material, consisting mainly of pieces of plus 38mm rocks that have been broken by further handling, is added to the rodmill feed.)

The average sorter feed consists of 20 per cent of relatively easily recognizable reef but in too small a size fraction for successful manual sorting, running at 13 g/t of gold, 65 per cent waste in many forms at an average value of 0.15 g/t, and a fairly indistinguishable fraction, which, although regarded as reef, generally has values below 0.7 g/t.

The sorter operates on the same daily schedule as the reef-picking plant—18 hours a day, six days a week. During the period under consideration, it operated for 93
per cent of the expected time, and received 180 000 t of feed, of which 28 per cent was sorted into the 'accept' fraction as reef at 6.5 g/t.

The efficiency for much of this period was well below expectation for reasons outside the sorter's sphere of influence, resulting in excessive quantities of waste rock reporting in the accept fraction, as well as the rejection of some reef. It is highly desirable with a machine of this nature that deviations from set operating parameters are confined. Unfortunately, this is not often possible. Interruption of the high-pressure air supply when problems were experienced with the plant's own compressor necessitated that lower-pressure mine air, which frequently fell below the minimum pressure required by the blast valves, had to be utilized. This adversely affected the efficiency through slow operation of the blast valves or insufficient blast energy to blast accepted rocks over the splitter plate. Badly worn blast manifolds, for which no replacements were immediately available, resulted in a dilution of the accept fraction. Both these problems have now been eliminated.

The installation was designed for 45 t of feed an hour and actually averaged 34.2 t an hour. However, for various reasons, the feed rate ranged from no feed to 80 t an hour. This variation was subsequently shown in tests to have limited effect on the sorting performance, which suggests that the capacity of the sorter may be increased in due course, but this will depend on the actual application.

Re-sorting of material that had initially 'gone the wrong way' usually resulted in the dilution effect being halved and a 10 per cent higher gold recovery in tests under better conditions. In other words, the sorter is capable of recognizing most of the rocks presented to it as reef or waste.

During this period, some 9 per cent of the material that was rejected by the main plant and would normally have gone to the storage dump was accepted by the sorter, and 325 kg of gold worth about R800 000 were recovered (at an average price of U.S. $115 per ounce).

During the period when there were no difficulties with air pressures, 81 per cent of the gold in the sorter feed was recovered. If it is remembered that the waste rock mined above or below the Carbon Leader Reef contains a small quantity of gold (on average 0.15 g/t), this 81 per cent is in fact a recovery of 86 per cent of the gold in the reef discarded from the main plant in the size range considered. Overall, the operation has resulted in an increase in recovery of 1.7 per cent of the gold in run-of-mine feed.

DISCUSSION

In many mineral deposits, and particularly in South African gold ores, the 'reef' occurs as a thin layer extending essentially in two dimensions. For practical reasons, however, it is necessary to mine varying amounts of waste with the reef, i.e., a minimum stope width is necessary for personnel to work in a stope. Desirably, this waste, which generally contains very little gold, should be separated from the reef, and for economic reasons at the earliest possible stage, when the rock is still at the maximum size at which the separation can be achieved. In practice, this usually results in the need for extensive hand-sorting operations, which require a large labour force. This is becoming increasingly costly as labour costs escalate. Hand-sorting is also extremely sensitive to fatigue factors, and sorting efficiency is usually inversely proportional to the period over which a sorting shift has continued.

A machine in which the operating costs escalate at a much lower rate than labour costs, and which has no fatigue factor and is independent of insufficient training or carelessness, has distinct advantages over manual sorting. If, in addition, it is also able to operate to sizes smaller than is practicable by hand-sorting, it becomes even more attractive.

The concept of automatic sorting is not new, but to date virtually all the equipment available has been limited by capacity and the inability to be confronted by the tonnages normally handled in large-scale mining operations. This is mainly due to the inability to deal with more than an in-line row of particles. Advanced electronic techniques, however, have now made it possible to sort a wide band of fast-moving, randomly oriented particles, as in the Model 13 Photometric Sorter described here.

The advantage of utilizing mechanical/electronic sorters like the Photometric Sorter can be summarized as follows.

1. If the limiting factor in a mine's metal output is the mill, its effective capacity will be increased by the sorting out of as much waste rock as possible. The discarding of waste at an early stage allows for increased mine output to be handled by the costly reduction plant and for a resultant higher metal production.

2. If, however, the mining rate cannot be increased without major capital expenditure, sorting will still be advantageous owing to the higher efficiencies and lower costs resulting from the treatment of a smaller upgraded tonnage.

At Doornfontein, the utilization of a small amount of mill capacity through a scavenger operation on a reject material has resulted in an additional 325 kg of gold to the mill in the first year of operation. At a gold price of U.S. $150 per ounce, this is worth R1 million and is achieved without additional mining costs and at low sorting costs. As this is a completely new operation, there are still many minor operating inefficiencies that can be eliminated, and a somewhat higher recovery can be expected.

The rapid increase in gold price in recent months is also favouring the sorting of the large quantities of low-grade rock dumps available on many South African gold mines. Take, for example, the following conservative case. If one assumes a dump containing 4 per cent reef at 20 g/t (0.8 g/t overall), a treatment rate of 170 t/h (1 million t/a), a 20 per cent accept when passed through a sorter (200 000 t) with 80 per cent metal recovery in the sorting and 90 per cent metal recovery in milling, 576 kg of gold worth R2...
One million at current gold prices ($162 per ounce) would result. On the assumption of reclamation, sorting, and milling costs of R500,000 (R2,500 per tonne of sorter accept sent as feed to the mill), a gross working profit of some R1.5 million a year can be expected. Allowance must still be made, however, for the capital cost of the sorter plant, the plant for dump recovery, and any additional milling equipment that may be necessary if no spare mill capacity is available.

The main reason for not installing further Model 13 sorters either as primary sorters and so increasing mill throughput capacity, or for dump recovery, is that more advanced techniques are under investigation, and there is a possibility that these could make the present model obsolete.

The sorting operation at Doornfontein is about as complicated as one is likely to encounter, and the Photometric Sorter will normally handle any feed where the valuable pieces in the feed can be distinguished from the less valuable (or barren) waste by observation. In its simplest form, it deals with light and dark particles, which is all that is required in many sorting operations.

Clearly, the possibilities of Photometric Sorting are inviting.

**FURTHER DEVELOPMENTS**

Subsequent to the successful commissioning of the Model 13 Sorter at Doornfontein, the Ore Sorters organization in Canada and South Africa have concentrated their efforts on developing sorters capable of discriminating particles down to 16mm square mesh size, a range well below that amenable to volume manual sorting.

This has required a new approach to the mechanical presentation and scanning systems. At a feed rate of 60 t/h in the range plus 16mm minus 40mm (double that of the Model 13 in this range), an average of 2 million particles per hour require to be separated and analysed. A sorter capable of performing this task is in an advanced stage of development.

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