Technical Note

Optimization of the operating density and particle size distribution of the cyclone overflow to enhance the recovery of the flotation of copper sulphide and oxide minerals

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Synopsis

The Konkola Mine, a subsidiary of the Konkola Copper Mines Plc (KCM) which is owned by the Vedanta group of companies of India and Zambia Consolidated Copper Mines Holding limited, is located at Chililabombwe in the northern extension of Zambia's Copperbelt province.

In its operations, the mine has been experiencing problems in ascertaining the optimum degree of fineness and the operating density of the hydrocyclone overflow in order to achieve high flotation performance. It was believed that recovery of sulphide copper minerals from Konkola ore is a function of the fineness of the grind so that it might be an economical justification to modify the grinding plant in order to run at lower cyclone overflow densities than the case is now.

In an effort to improve these operations, it was decided to carry out test work on various hydrocyclones of sizes 0.381 m, 0.4575 m and on 0.508 m. The later was found to give satisfactory results and was installed on the plant. Despite giving satisfactory results there was need to investigate further to establish the working densities and size.

Increasing the density of cyclone overflow decreases the per cent passing 75 μm at least in the range 1 080–1 150 g/ℓ. Furthermore, hydrocyclones give better separation at low densities of feed and hence the efficiency is high at low feed densities. Circulating load increases with an increase in feed densities and an decrease in the grind. The flotation performance in both sulphide and oxide copper minerals rougher stages is enhanced with an increase in the degree of fineness of the grind, with an optimum being obtained at a density of 1 150 g/ℓ and 81.4% passing 75 μm.

Keywords

Konkola mine, hydrocylone, optimum degree of fineness, sulphide copper minerals.

Introduction

Background

The Konkola Mine a subsidiary of the Konkola Copper Mines Plc (KCM), which is owned by the Vedanta group of companies of India and Zambia Consolidated Copper Mines Holding limited, is located at Chililabombwe in the northern extension of Zambia's Copperbelt province. Since its inception, Konkola copper mine concentrator operation has consisted of processing copper-bearing ores to produce copper concentrates which are later sent to the pyrometallurgical plants in either Kitwe or Mufurila. The main copper-bearing minerals found at Konkola Mine include bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S) and native copper (Cu).

The mine has been experiencing problems in ascertaining the optimum degree of fineness and the operating density of the hydrocyclone overflow in order to achieve high flotation performance. It was believed that recovery of sulphide copper minerals from Konkola ore is a function of the fineness of the grind so that it might be an economical justification to modify the grinding plant in order to run at lower cyclone overflow densities than the case is now.

It was against this background that the technical staff of Konkola concentrator proposed an investigative work to determine the relationship between density and size distribution of the hydrocyclone overflow product so as to optimize the operating density and particle size distribution of the cyclone overflow.

The Konkola concentrator has a number of unit operating plants ranging from washing, secondary and tertiary crushing, screening, grinding, and flotation to drying plants.

The milling plant where this project was carried, out consists of thirteen grinding units of which eleven are small (2.75 m × 2.44 mΦ). These small units are each now in closed circuit with one 0.508 mΦ hydrocyclone. The remaining two big units (4.27 m by 3.35 mΦ) each are in closed circuit with two 0.508 mΦ hydrocyclones of which one is usually on standby.

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Hydrocyclone operation

A hydrocyclone is a continuously operating classifying device that utilizes centrifugal force to accelerate the settling rate of particles. Since its inception, it forms one of the most important devices used in the mineral dressing industry (Wills, 1988).

As a classifier, the hydrocyclone has proved extremely efficient at fine separation sizes and is increasingly used in closed-circuit operations, but has found many other uses such as desliming and thickening.

As shown in Figure 1, a typical cyclone consists of a conically shaped vessel, open at its apex (underflow), joined to a cylindrical section, which has a tangential feed inlet. The top of the cylindrical section is closed with the plate through which passes an axially mounted overflow pipe. The pipe is extended into the body of the cyclone by a short, removable section known as the vortex finder, which prevents short-circuiting of feed directly into the overflow.

The vortex in the cyclone is generated by the tangential feed entry into the cyclone under pressure. This imparts a swirling motion to the pulp.

As feed enters the chamber, a rotation of the feed begins causing centrifugal force to act on particles that have sufficient mass, moving them towards the outer wall of the cyclone as more fluid enters the chamber; the particles migrate downwards in a spiral pattern into a conical section. At this point, the smaller mass particles begin to migrate towards the centre and spiral upwards and out through the vortex finder as an overflow. The heavy particles remain in their downward spiral path along the walls of the conical chamber and eventually work their way out through the apex opening as an underflow (Gilchrist, 1989).

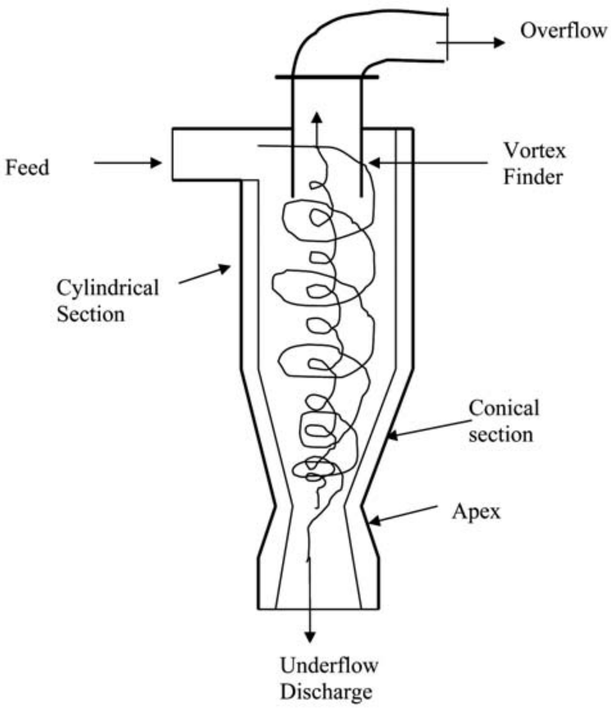

Figure 1—The hydrocyclone

Feed inlet

The area of the feed inlet determines the entrance velocity, and an increase in area increases the flow rate. The geometry of the feed inlet is also important, and in most cyclones the shape of the entry is developed from circular cross-section to rectangular cross-section at the entrance to the cylindrical section of the cyclone. The inlet is normally tangential, but involute feed entries are also common. This sets the entering feed to swirl as it enters. This causes a spiral-like shaped path.

Vortex finder

The vortex finder prevents short-circuiting of feed directly into the overflow and also allows the outflow of fine particles into the overflow pipe. The diameter of the vortex finder is a very important variable. An increase in the diameter of the vortex finder at a given pressure drop across the cyclone will result in a coarser separation and an increase in capacity. On the other hand, a smaller vortex finder normally means a finer cut-point.

Spigot opening

This determines the underflow density. It must be large enough to discharge the coarse solids that are being separated by the cyclone. In order to establish the air vortex, the opening must permit the entry of air along the axis of the cyclone. Under normal operating conditions, the underflow should be discharged in form of a hollow cone spray at the highest possible density.

Too small an apex opening can lead to the condition known as 'roping' where an extremely thick pulp stream of the same diameter as the spigot opening is formed, and the air vortex may be lost, the separation efficiency will fall, and oversize material will discharge through the vortex finder. Too large an apex orifice results in the large hollow cone pattern. The underflow will be excessively dilute and addition of water will carry unclassified fines solids that would otherwise report to the overflow.

Cyclone efficiency

The usual and commonest method of representing cyclone efficiency is by the tromp, partition or performance curve, which relates the weight fraction or percentage of each particle size in the feed, which reports to the apex (underflow) to the particle size. In the cyclone operation, the cut-point is often defined as that point on the partition curve for which a particle in the feed has 50% chance of reporting to the overflow or underflow and is often referred to as the d_{50} size. The slope of the central section of the partition curve determines the sharpness of the cut, and the closer to vertical the shape, the higher the cyclone efficiency. By taking the d_{75} and d_{25} point at which particles of the feed have 75% and 25% chance of reporting to the underflow, the slope of the curve can be determined. The efficiency of separation or imperfection I is given by

$$I = \frac{d_{75} - d_{25}}{2d_{50}}$$

Many mathematical models of hydrocyclones include the term corrected d_{50} taken from the corrected partition curve. This is shown on Figure 3.

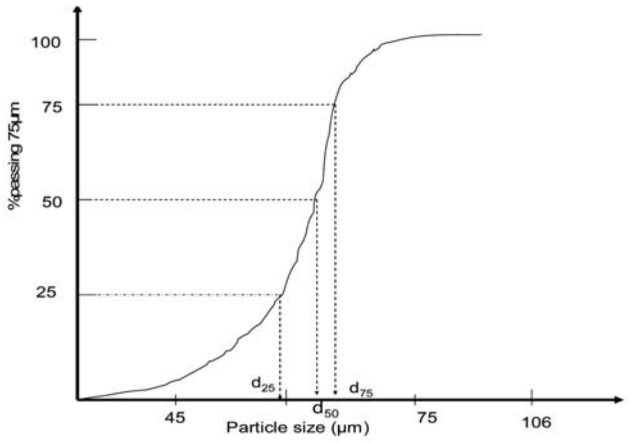

Figure 2—Partition curve for hydrocyclone

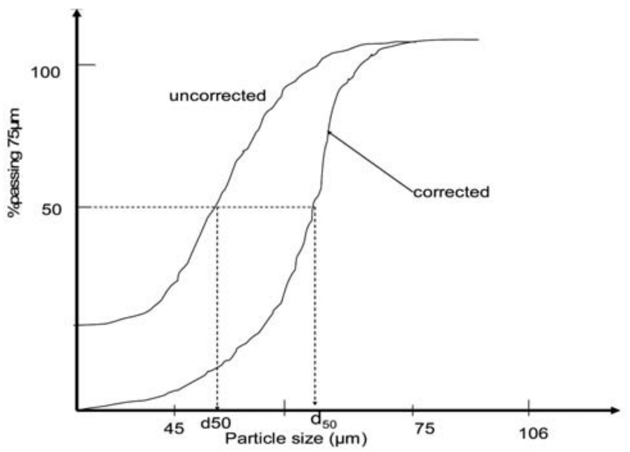

Figure 3—Uncorrected and corrected partition curves

Factors affecting cyclone performance

The effect of changing operating and design parameters in cyclones is very complex in that all parameters are interrelated. It is almost impossible to select a cyclone to give the precise separation required, and it is nearly always necessary to adjust feed pressure, vortex finder, apex opening, and dilution.

Pressure drop

The pressure drop must be maintained for good cyclone operation. The pressure drop can vary but it can be maintained by keeping an adequate sump level. When the sump level goes down considerably, the pump will cavitate and the pressure drop at the cyclone will go to nearly zero. During this transition, coarse solids will report to the overflow, and once the pressure drop reaches zero, all the slurry in the cyclone will report to the underflow.

Density of feed

The density of the feed has by far the largest impact on cyclone performance. When operating at a feed density above 50% solid by weight, small changes in the density of the feed will change the separation performance dramatically. The cyclone should always be operated at the lowest density of the feed possible while still maintaining the required separation and overflow density.

Apex opening

The apex must be sized to allow a cone shaped discharge (ideally 20–30° included angle) at maximum condition. Increasing the apex opening decreases the separating size, i.e. the overflow becomes finer.

Froth flotation

Flotation is undoubtedly the most important and versatile mineral processing technique whose both uses and applications are being expanded to greater extents and to cover new application areas since its inception in 1906 (Wills, 1988).

It is a process that can be used to achieve specific separation of complex ore such as Cu- Zn. Froth flotation utilizes the difference in physico-chemical surface properties of particles of various minerals (Jan, 1982).

Therefore, in froth flotation, use is made of the differences in the wettability of mineral surfaces. In a mixture of liquid (water), gas (air) and various solid species (an aerated pulp), the species with a greater affinity for air will attach themselves to them, while species with greater affinity for water will, remain dispersed in the pulp. The air bubbles with the mineral that are attached to them rise to the surface as a froth so that mineral separation is achieved.

Substance with greater affinity for water are called 'hydrophilic' (water-friendly or wettable) whereas those with greater affinity for air are hydrophobic.

Only few minerals are naturally hydrophobic, but many minerals (as well as many synthetic compounds) can be made hydrophobic by the adsorption of certain surface active reagents are either collectors or frothers.

Flotation reagents

Collectors

Most collectors are weak acids or bases and their salts. These may be anionic or cationic and should dissociate in water. They are anionic if the anion is the active part or cationic collector if the active part is the cation. The active part is the heteropolar, i.e. one end carries the electric charge that is responsible for the reaction with the mineral surface. The other end is a long hydrocarbon chain that is directed towards the pulp when the collector ion reacts with the mineral surface. This makes the surface of the mineral become hydrophobic.

Frothers

Frothers are surface-active reagents that aid stabilization of air bubbles, bubbles coalesce and lowering of surface tension. Frothers are generally heteropolar surface-active organic reagents that are capable of being adsorbed on the air-water surface. All frothers may have an active or polar group which may contain oxygen as in hydroxyl (-OH), carboxyl, aldehyde (-CHO) or (=CO) group (Jan, 1982), and nitrogen as in the amine or amide (CO.NH-)

Modifiers

These are reagents that tend to promote functions of specific flotation reagents. Modifiers used to either suppress a mineral during flotation or promote its acceptance are called depressants and activators respectively. Modifiers such as lime can control the pH, but lime contains a calcium ion, a known depressant for pyrite in copper flotation. At different pH values the same reagent can be a depressant as well as an activator.

Flotation of sulphide minerals

Sulphide minerals are easily floated with anionic collectors. The most commonly used collectors for sulphide flotation are xanthates. These are used in alkaline pH range by adding lime to the discharge in the grinding circuit. In concentrating mineral sulphide, advantage is taken of the difference in the surface nature of the mineral species to separate the collector coated valuable sulphide from the more hydrophilic sulphide and non-sulphide gangue. The behaviour of some sulphide gangue e.g. pyrite (FeS_2) is more or less similar to that of valuable sulphide except that the rates of flotation are much slower. (Forsseberg, 1979).

There are two mechanisms by which particles are transferred from flotation pulp into concentrates. These mechanism are, the adhesion of air bubbles with natural flotation and the entrainment of particles in the froth. The adhesion of collector-coated sulphide mineral surfaces to air bubbles is a very important mechanism for the recovery of sulphide minerals. The entrainment mechanism in which pulp is entrained in the bubble mineral aggregate and carried over into concentrates is responsible for the recovery of free non-sulphide gangue. The former mechanism is more selective with regard to the character of the ore as this determines the extent to which the particles can be made hydrophobic. The later is more selective for particle size and specific gravity.

Flotation of oxide minerals

Most metallic and non-metallic oxidic copper minerals e.g. oxides, carbonates, phosphates, silicates of copper, etc. are much more difficult to recover by flotation because they do not readily respond to the thio-collectors. The flotation of oxide minerals may, however, be made possible after sulphidization. In the absence of sulphidization an oxide particle is surrounded by a comparatively thick metal hydroxide layer which is hydrophilic. Sulphidization makes the surface pseudo-sulphide which then, with only small amounts of xanthates, will be rendered hydrophobic. Ionic collector used for these minerals include various fat acids and their soap, organic sulphates and sulphonates.

Cationic collectors are mainly amines. All these collectors require conditioning time to affect their interaction with mineral surfaces. Conditioning tanks are used between thickening and flotation stages.

The correct amount of each reagent is critical for adding to the flotation tank. Too much collector decreases the recovery due to the formation of collector multilayer micelles on the particle surface (Wills, 1988).

Brief description of flotation mechanism

Flotation can be defined as a macro process comprising a number of micro processes taking place simultaneously and successfully in time and space. It is important to understand the various physico-chemical processes, which take place during this process in the flotation cell. These are:

- Homogeneous suspension of a bubble
- Introduction of air as a small dispersed bubble
- Turbulence agitation of pulp to enhance particle dispersion
- Stable froth formation and transfer of mineral value into a quiet zone known as launder.

The theory of froth flotation is a complex and is still not completely understood, and the process can be applied only to relative fine particles.

The attachment of solid particles to air bubbles is the most important stage of flotation. As early as 1932, particular special attention was paid to the kinetics of thinning of the intervening film between an air bubble and a mineral surface, leading to the suggestion that this film thinning can be seen as a means of interpreting the mechanism of froth flotation.

For the successful bubble-particle attachment, three elementary steps are important (Schulze,1981):

- Thinning of an intervening liquid film to a thickness h_{cr}
- Rupture of an intervening liquid film and formation of a three-phase contact (TPC) and
- Expansion of TPC line from the critical radius to form a stable wetting perimeter.

The attachment of a particle to a gas bubble in a flotation system is usually described as a result of a series of probabilities described below.

- Probability of bubble-particle collision in the pulp (P_c)
- Probability of bubble-particle adhesion (P_a)
- Probability of non-detachment between particle and bubble (P_d).

Then the overall probability of a successful flotation can be expressed as a product of the above probabilities, as below.

$$P_f = P_c.P_a.P_d \qquad [1]$$

The empirical simplification used to model a flotation process will take into account the steps mentioned above, and the simplest form of kinetic equation describing flotation is the evaluation of mineral particle number per unit time in a given volume of apparatus.

$$\frac{dn}{dt} = -z.n_p.n_b.P_c.P_a.P_{st}.P_{tpc} \qquad [2]$$

where P_c, P_a, P_{st}, and P_{tpc} are probabilities of bubble-particle collision, bubble-particle attachment, stable froth and three-phase contact respectively. The n_p and n_b denote the number of particles and bubbles respectively.

Materials and methodolgy

Grinding and density evaluation

- For each test, 0.508 mΦ hydrocyclone overflow, underflow and feed were sampled for sizing and density determination for 5 to 10 times using a linear sampler to give about 2.5 kg
- After collection, each sample was subject to density determination by using the laboratory pulp density scale, then filtered in the laboratory compressed air filter, dried at 90–110°C in the laboratory oven after which they were thorough homogenized.

- ➤ 100 g of each sample was subjected to screen analysis by washing it on 75 µm sieve to determine the per cent passing 75 µm.
- ➤ Another 100 g of each sample was screened through a deck of sieves composed of 106, 75, 53, and 45 µm.
- ➤ 50 g of each overflow sample collected at different densities, hence having different per cent passing 75 µm, were sent for assaying, and about 2 kg stored in sealed plastic to prevent any oxidation was subjected to flotation at a later time.
- ➤ After flotation, the concentrates obtained were sent to the assay laboratory for per cent total copper (%TCu) and acid soluble (%ASCu) copper analysis.

Flotation

Samples were removed from sealed plastic for preparation in the shortest possible time before flotation to avoid any form of oxidation. The samples were weighed and as a precautionary measure, the moisture content was estimated to be as low as possible.

- ➤ During flotation, the standard flowsheet was used and the reagent dosages were as shown in Figure 4.
  - Each of the samples collected and stored in sealed plastic was put into a 2.5 litre flotation cell to which water was added to fill up to a 2.5 litre mark.
  - Conditioning of the flotation cell content was being done in 1.5 minutes after which the air valve was opened and the first four concentrate fractions were collected in the time interval indicated. This forms sulphide flotation.
  - The fifth concentrate fraction, which was collected as an oxide rougher concentrate was floated as a result of the addition of what are called buster reagents followed by 1.5 minutes conditioning time.
  - For each sample subjected to flotation, the five concentrate fractions collected were filtered, dried at a reasonable temperature, weighed, and taken to the assay laboratory for %TCu and %ASCu.

Results and discussions

Grinding and density evaluation

From Figure 5, it can be seen that there is a linear relationship between overflow density and sizing

It can also be seen from the graph that the gradient is slightly in the density region 1 080–1 130 g/ℓ. Although obscured by experimental errors the gradient is evidently in the density region of a rise of 1.5% passing 75 µm for a 30 g/ℓ drop in the cyclone overflow density.

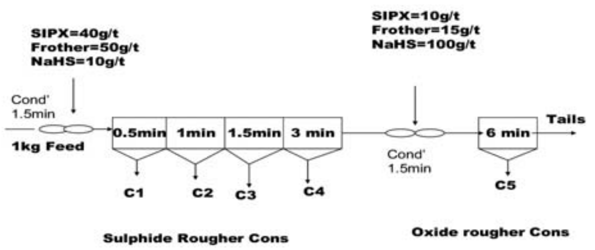

Figure 4—Konkola concentrator standard laboratory flotation flow sheet

Particle size distributions of hydrocyclone overflow (screen analysis)

Figure 6 shows the relationship between cumulative weight per cent passing and particle size of the cyclone overflow taken at different densities.

Observation can be made from Figure 6 that efficiency of separation increased with an increase in the cyclone overflow density up to 1 123 gpl beyond which a decrease in efficiency was exhibited.

The explanation for this observation is that, when the feed density increases, slurry viscosity also increases and the cyclone separation coarsen (Mainza, 2004). Some irregularities from the above observation could be due to the fact that, during screen analysis fine particles tend to stick together or cling to large particles, thus giving rise to some deviations from the expected results.

Circulating load at various feed density

Figure 7 shows that as the feed density increases, the circulating load increases. The explanation made to this observation is that, as the feed density increases, the slurry viscosity also increases and the cyclone separation coarsens.

If the cyclone produces a finer separation than the mill is capable of grinding, then the circulating load will build up until the cyclone feed density increases to the point of a coarser separation and the mill comes to equilibrium.

Flotation performance

The assays from all the eight samples collected at different densities of cyclone overflow and hence different sizes, showed that the copper content of each sample ranged between 2.7 wt% and 3.3 wt%.

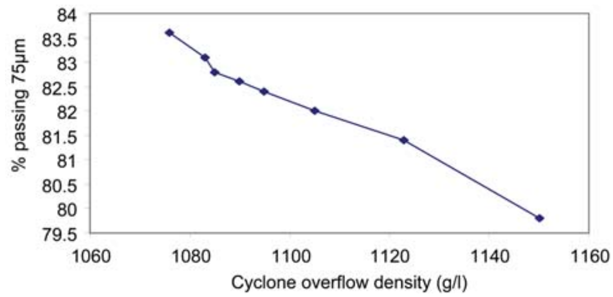

Figure 5—Relationship between density and sizing of hydrocyclone overflow

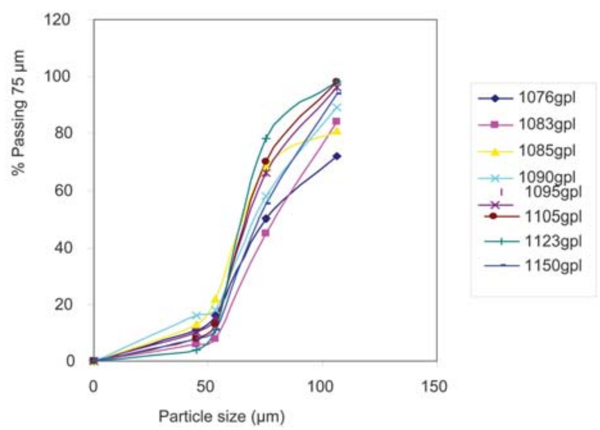

Figure 6—Particle size distribution

Figure 8 shows that total copper recovery increases as the cyclone overflow density increases. At 1 150 g/ℓ the rate of recovery was highest, as seen by the steepness of the curve in the first 180 seconds of flotation. The recovery at the density of 1 123 g/ℓ and after flotation is over was suspected to contain some errors as most of the graphs were flat and converged almost at 90.52%. The recovery observed at a density of 1 123 g/ℓ is obviously as a result of some experimental error as it is practically impossible to have 100% recovery under plant conditions (Deelder,1996).

Figure 9 shows a plot of total copper recovery against cyclone overflow density. It is observed that total copper recovery increases as the density increases up to 1 123 g/ℓ were it was seen to start decreasing. The observation made at a density of 1 123 g/ℓ is no doubt a subject of some errors which could have manifested from either the reported assay from the analytical section or during the % recovery calculations. It is practically impossible under plant condition to obtain 100% recovery. Although the test was not done on densities above 1 150 g/ℓ, the trend of the results showed that the recoveries would still be decreasing at greater densities. Moreover, densities greater than 1 150 g/ℓ would require a very large addition of water.

Figure 10 shows that the total copper recovery increases as the amount of material passing 75 μm increases up to 81.4% where it was seen to remain constant. This confirms the fact that recovery of sulphide copper at Konkola like at any other mine, is a function of the grind up to some optimum particle size (mesh-of-grind) say at 81.4% passing 75 μm, beyond which recovery is not seen to improve.

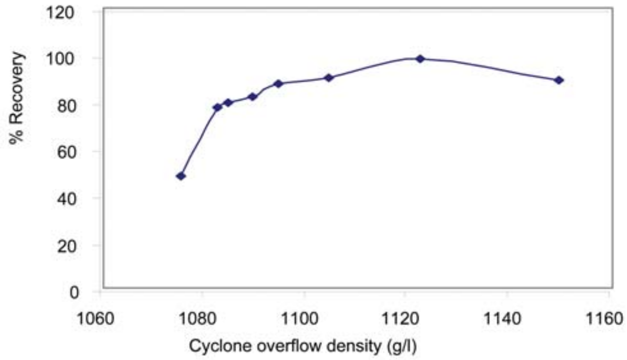

Figure 9—Average effects of cyclone overflow density on recovery

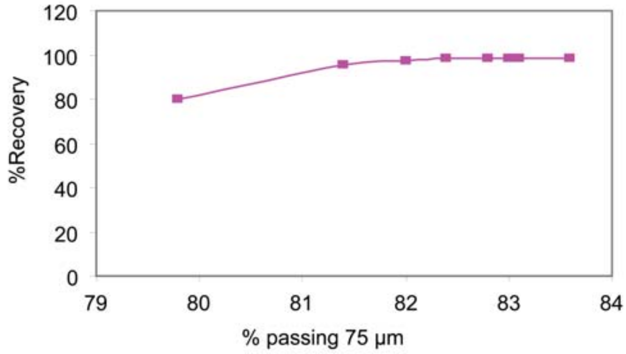

Figure10—Effect of grind on flotation performance

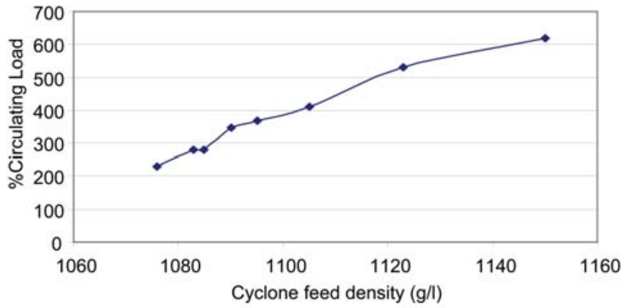

Figure 7—Effect of feed density on circulating load

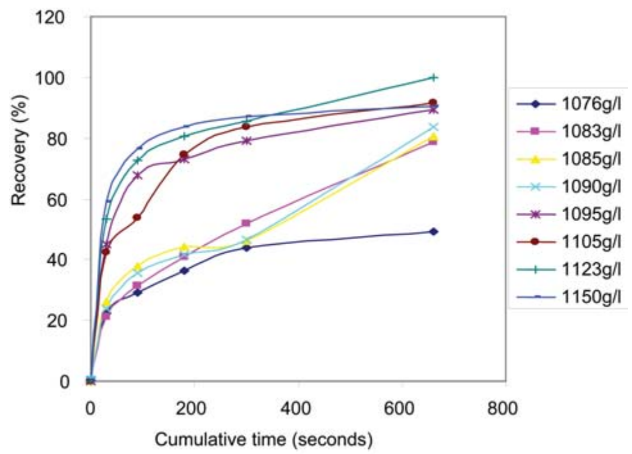

Figure 8—Effect of cyclone overflow density on flotation performance

Conclusions

From the investigations done at Konkola concentrator on hydrocyclone feed, overflow, underflow densities and grinding, it was established that there is a strong linear relationship between cyclone overflow density and sizing. Increasing the density of cyclone overflow decreases the per cent passing 75 μm at least in the range 1 080–1 150 g/ℓ. Furthermore, hydrocyclones give better separation at low densities of feed, and hence the efficiency is high at low feed densities. Circulating load increases with an increase in feed densities and an decrease in the grind. The flotation performance in both sulphide and oxide copper minerals rougher stages is enhanced with an increase in the degree of fineness of the grind with an optimum being obtained at a density of 1 150 g/ℓ and 81.4% passing 75 μm.

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