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## **Analysis of the Effects of Grind Size on Production of Copper Concentrate: A Case Study of a Mining Company in Zambia**

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### **Abstract**

A mining company treats underground ores of complex mixture of copper sulphide and small amount of copper oxide minerals. However, a number of flotation parameters have not been optimized to meet concentrate standards and grind size is one of the parameter. The purpose of this research project was to analyze the effect of grind size on concentrate production at a mining company in Zambia. The researcher set objectives which were to determine the current grind size and the output obtainable and also to determine the grind size and range of grind size that will produce the most concentrate. Literature relevant to answer the research questions was reviewed. The research design used was experimental in which direct observations and laboratory experiments were used to gather data. Samples from the ball mill feed were collected for the investigations at the mine laboratory. Laboratory flotation tests were carried out at various levels of grind; namely 15.33%, 19.52%, 28.16%, 39.47% and 51.51% passing 75microns sieve aperture, For each test, timed flotation concentrates were collected at intervals of 0.5, 1, 1.5 and 4 minutes. Natural pH level was maintained for all the tests. The results have shown that increase in the fineness of grind was accompanied by improvement in the recovery of values. The highest recovery of 94.482% was obtained at the finest grind (51.51% passing 75microns) used in the tests.

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The trend did not attain terminal values, an indication that further increase in the fineness of grind may still result in improvement in the copper recovery as compared to the current plant recovery of 87% achieved at the grind of 40% passing 75microns. From the results obtained, the researchers recommended that further tests can still be carried out at finer grinds until optimal recovery values are obtained.

**Keywords:** Analysis; Concentrate; Grind Size; Production.

## **1. Introduction**

Concentrates are produced through a complex process called flotation which is a process of floating valuable minerals and sinking gangue particles by utilizing various physical characteristics of the minerals involved. It commences by comminution, a process of crushing and grinding used to increase the surface area of the ore for subsequent processing and breaking of the rocks into the desired mineral and gangue in a process known as liberation [1]. Wills, continues, that for the process of flotation to take place effectively and efficiently many parameters should be well adjusted including an optimized size distribution of grains i.e. grind size, that will allow as much valuable resource to float and retain gangue as much as possible to the tails. Grind Size refers to the percentage distribution of fine ground ore when screened through a chain of subsequent screening sieves, [2]. The process department at the mine, embarked on testing various parameters that could be adjusted in order to fully optimize the plant capacity. These ranged from the analysis of mineral composition of the feed, the rate of feeding the plant and residence time of the process to analyzing the effects that grind size of the ore can have on copper concentrate production during flotation process. Therefore this research was more focused on determining whether the size distribution of the ore after comminution would cause significant impact on copper ore response in the floatation process. Comminution processes at the mine accounted for 49.8% of the total costs of production, i.e. 47% grinding to achieve a perfect liberation and 2.8% crushing costs meaning the overall results of the research would help the metallurgical department to make a sound decision with regard to comminution, in that, there would be a balance between production costs and overall production returns. Optimization of the grind size could lead to the maximum liberation of the copper, therefore increased productivity and high quality concentrate would be produced. According to Williams [3], productivity is the measure of the extent to which the resources of an organization are being used effectively in transforming inputs into useful outputs. In the production of copper concentrate, productivity is the efficiency with which the low grade copper sulphide /oxide ore is concentrated into high grade copper concentrates. The process of conversion, in copper or any mineral concentration process is known as beneficiation, because it involves the aggregation of low concentrated valuable minerals between 0.9% and 5% into high grade between 15 and 50 % that can be economically treated without excess wastage of reagents. The beneficiation process of copper sulphide and oxide minerals is a complex process that commences with; comminution of the ore, setting right densities, correct reagent mix, and optimum flows that maximize the residence time of recovery. Sweboda [4], stated that, comminution involves the progressive reduction of particle size to cleanly liberate particles of valuable minerals such that, they can be freely separated by froth flotation or magnetic separation should they render ferric properties and therefore, the objective of comminution in this research was for mineral liberation. In the mine plant, crushing reduces the particle size of the of mine ore to the size suitable for grinding to a size which is such that mineral and gangue are substantially produced as separate particles [5].The comminution

process is therefore a progressive process which is required to reduce the size of the raw material progressively in order to have an even distribution of grains without extreme variances so as to balance between gangue floatation and valuable mineral losses to the tails. Comminution of ore involves the following steps;

- Crushing: comprises of primary crushing, secondary crushing and then tertiary crushing. The core purpose is to reduce ore from around 600mm to 200mm with product distribution of about 20% passing 14mm.
- Grinding: This is the final stage of the comminution process and its main purpose is to achieve good mineral liberation of about 40 to 45% passing 74microns before flotation process begins.

The process of flotation commences with the thickening process which is done mainly to adjust the pulp density of the slurry from the storage tank in order to achieve the best results, in terms of reagent use, reaction surface area and flotation activation. When slurry is pumped from the storage tank at about 40% solids, it is flocculated in the thickener. The solids coagulate and sink to the bottom; clear water is recycled as overflow and the under flow pulp is then pumped to the flotation section at about 65% solids, [6]. The process of flotation is known as froth floatation which is a process of ore concentration involving the segregation of the minerals in ore into concentrates containing the valuable minerals and tailings containing gangue components of an ore which is often worthless. According to Wills [7], the differences between valuable minerals and waste gangue are increased through the use of surfactants and wetting agents and the selective separation of the minerals thus makes processing of complex (i.e. mixed) ores economically feasible. The flotation process is therefore used for the separation of a large range of sulphides, carbonates, and oxides prior to further refinement. Figure 1 is a depiction of the froth floatation process.

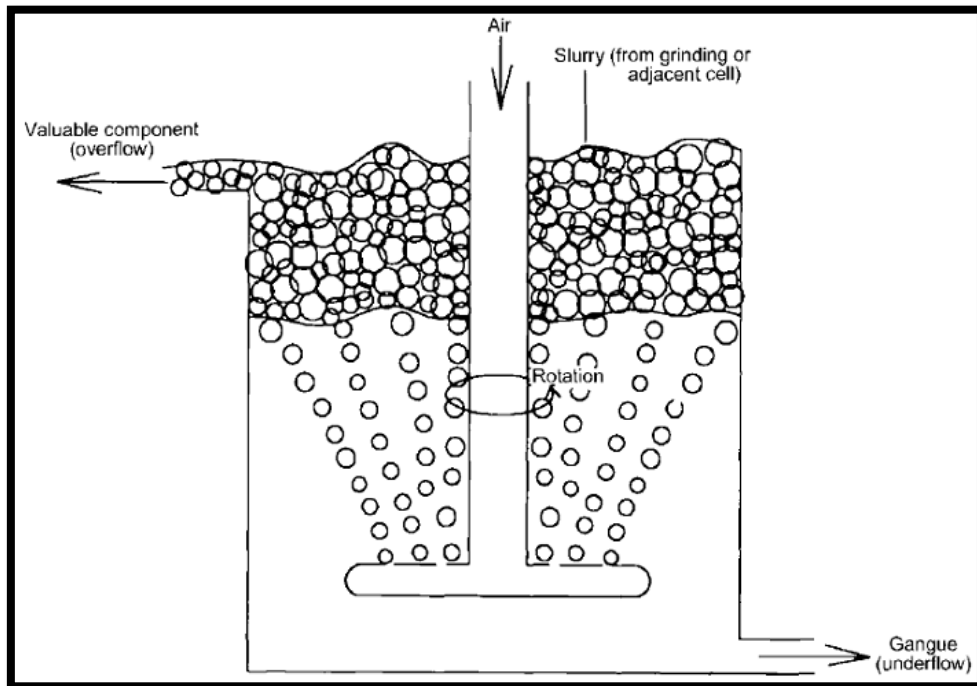
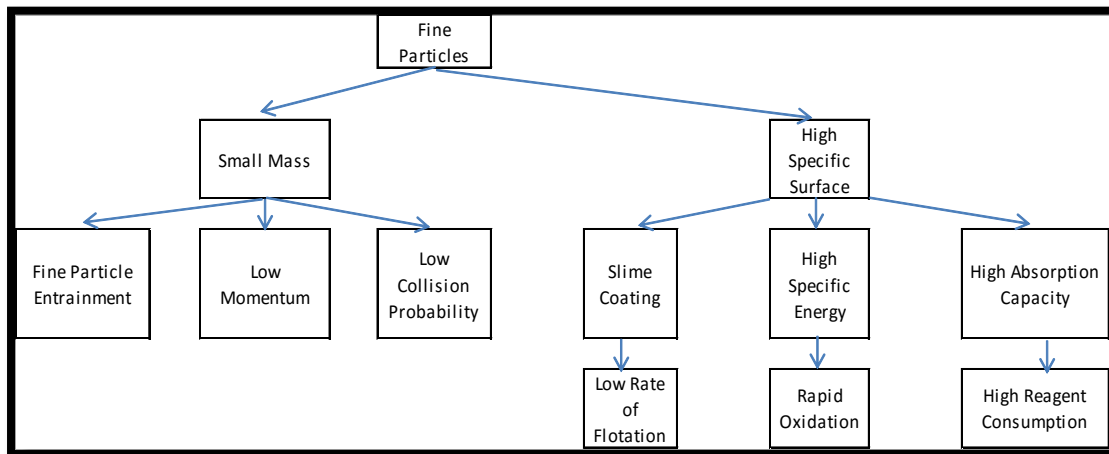


Figure 1: Flotation Cell during flotation of the ore

According to [8], the essence of flotation processes is the concentration of the finely divided minerals on the basis of variations in their ability to keep themselves on a phase interface. [9] also affirms that it is a means of treating a pulp of finely ground ore so that the valuable or desired mineral is obtained in a concentrate which will be amenable for further processing. The process involves imparting a water repellent (hydrophobic) character to the desired mineral particles with the aid of chemicals that are called collectors or promoters. Under favorable conditions, these chemically coated particles become attached to the air bubbles rising through a pulp and thus “float” to the surface. This process is affected by a number of factors such as flotation time, grind size and contact angle for effective response. The researchers in this research assumed the mined ore had been crushed in stage by a jaw crusher followed by secondary crushers to a product of maximum size of 3 to 15 mm in diameter. This crushed ore was then taken to rod or ball mills for grinding to the size required for flotation. From grinding mills, the pulp was fed to classifiers e.g. Cyclones, which returned the coarser particles to the mill for further grinding. According to [10], fineness of grind is the single most effective control action influencing the performance of the ore in a flotation plant but in practice, this could mean a reduction of the ore to slimes, which are amenable to flotation. Figure 2 shows the relationships and the effects of the various sub – processes on flotation. The most direct effect of particle size can be observed in the reduction of the rate of flotation and recovery as the particles decrease in size.



**Figure 2:** Relationship between the Physical and Chemical properties of fine particles and their behaviors in flotation [10]

## 2. Materials and Methods

This section describes the method employed to collect and process data for the study. The researchers used both primary and secondary data in the current study. Primary data was collected through experiments and observations while secondary data was collected from company official production reports, company manuals and standard operation procedures

### 2.1 Experimental Material-Base Case

The current study is based on ore mined in Chibuluma South area of Kalulushi Town in Zambia-Copperbelt

Province. The feed grade varies from 2.5 to 5% TCu at a milling rate of 40tonnes/ hour. The indicated average concentrate grade is 50% TCu at 95% plant recovery. The existing grind size for the blended ore is 52% passing <75microns

## ***2.2 Specific Methodology***

The first phase was observing the plant layout aimed at recognizing the best points to collect a good representative sample. The point was identified as the Ball Mill feed from primary crushing section. Grab samples were collected from the ball mill feed in the morning and afternoon shifts for 24 days using metal buckets. The samples were then poured on trays and left to dry overnight in the oven each time they were collected. This was done to minimise moisture. Naturally dried samples would then be packed in respective day sack.

## ***2.3 Sample Preparation***

The ore samples for all the batches were sized using a Jaw crusher and then Cone crusher to reduce to 100% passing 8mesh (2.36 mm) then mixed thoroughly to create one homogeneous and representative sample through coning and quartering. The crushed samples would then be split into 1kg batches for laboratory tests.

## ***2.4 Grind Time Determination***

The purpose of this was to plot a grinding time against grind size curve, to guide the grind size needed just by using residence time in the mill. A mill ball charge of 5kg of different size was prepared. 1kg of prepared ore was feed in with 500ml (0.5 liters) of water to create a 65% solids pulp, the standard density for the concentrators. Five, (5), 1kg lots of samples were ground at different grind times namely, 5, 10, 15, 20 and 35 minutes respectively. The ground samples in pulp form were subjected to filtration using pressure filters, and the resulting cake was dried in the oven for 3hours.

## ***2.5 Sieve Analysis***

The purpose of this analysis was to know grind size distributions for each grind time using sieve analysis. The dried samples were mixed thoroughly using cone and quartering technique so as to have homogenous samples. Then 300g of the representative sample was taken and placed in a -38microns sieve tray and screened using water pressure, this was so to ensure that all slimes are forced out by water, a process called wet sieving. This was done continuously until the water was clear from the bottom of the tray. The remaining grains called +38microns was dried in the oven with the weight of the empty tray already known. After 1 hour, the tray was cooled at atmospheric temperature. The tray was now weighed with the dry sample and recorded. Then it was placed on the chain of sieves to find grind size distributions. The chain consisted of 300, 212, 150, 106, 75, 53, and 38 microns.

The sequence of the sieves was obtained by multiplying the square root of two to get the next sieve. The chain of sieves was then closed up and tightened to the Denver sieve shaker, and shaken for 15mins for each stream.

With the weights of all empty sieves pre known, the individual sieve fractions retained on each sieve were weighted on an electronic balance and results recorded for each sieve. The percentage weights retained for each sieve were calculated.

## **2.6 Chemical Analysis**

The process of chemically analyzing the ore for mineral content is called Assaying. A separate lot was taken from the sample stock and analyzed for total copper (TCu) and Acid soluble copper (ASCu). This was done on 5 samples for establishing the average grade of the copper content of the sample.

## **2.7 Flotation**

Laboratory flotation tests were carried out using Denver flotation machines. Below is the figure of Denver flotation machine. During this stage, in the mine assaying laboratory, five (5), one (1) kg samples were weighed to run five flotation tests. Cone and quartering method was used for partitioning. Each of these samples was ground at different grind sizes using the grind time curves, between 5 and 35 minutes. The ground samples were fed to the 2.5 liter cell capacity Denver flotation machines at various grind sizes, process water, which is the recycled water with varying percentage of reagents, was added to the samples yielding two (2) liters slurry.

The flotation cell was then positioned upright and agitated with a rotor. As the slurry agitated, a collector called SIPX (Sodium Iso-Propyl Xanthate), of about 30g/t and 2 to 3 drops of a frother, Beta Froth, was added. The rotor speed was maintained at 2000rpm and conditioning time 1.2 minutes was given for reaction time, mixing reagent and pulp. After 1.5 minutes an air valve was opened, slowly, until a steady flow of froth was discharged. The total residence time in flotation was seven minutes. The overflowing froth of minerals was the concentrate collected. Concentrates were collected in the intervals of 0.5, 1, 1.5, and 4 minutes, for each grind size processed. The collected concentrates and tailings were dried in the oven and weighed after cooling. Thereafter, from all labelled samples, both tailings and concentrates, 0.5g samples were taken and sent back to the assaying laboratory for mineralization analysis.

## **3. Results**

Results of the current study are very interesting. The percentage of particles passing 75 micron was found to increase with increase in grinding time. This means that the longer the grinding time the finer the ground ore particles as shown by fig. 3.

The flotation kinetics shown in Fig. 4 at 39.47% and 51.51% passing 75 microns are somehow the same. The same observation can also be made on flotation kinetics at 19.52% and 28.16% passing 75 microns. The terminal recoveries are attained within three minutes of flotation time at most of the levels of grind. In general as the fineness of the grind increases, the flotation response of study ore improves. The highest recoveries are attained with 39.47% passing 75 microns with terminal recoveries at 90.315%. Increasing the fineness of grind to 51.51% passing 75 microns resulted in marginal improvement in the copper recoveries to 94.482% as shown by fig. 5.

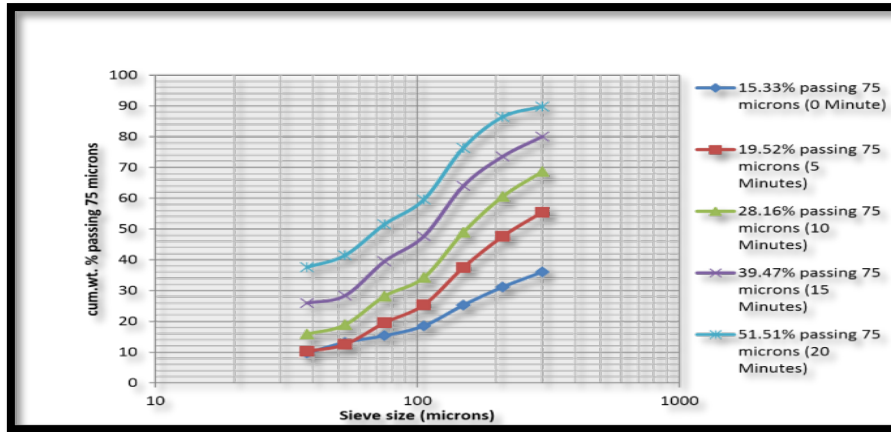


Figure 3: Cumulative weight percent passing against Sieve Size at different levels of grind

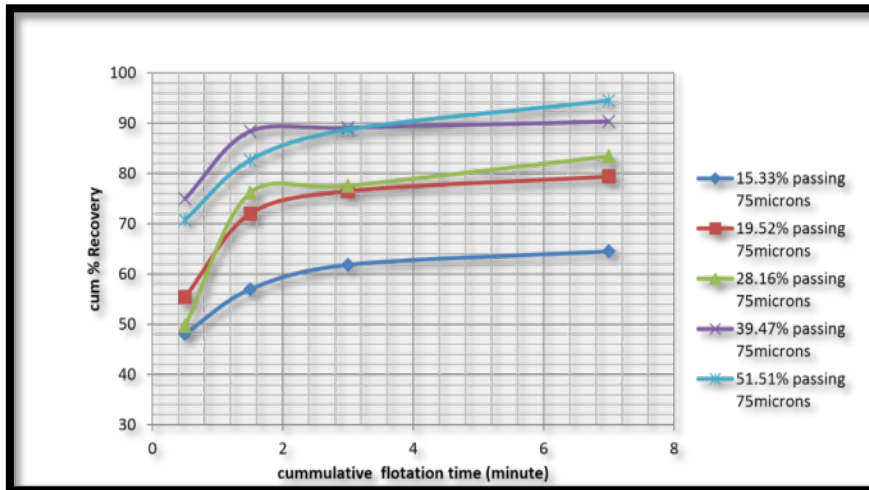


Figure 4: Concentrate recovery against grind time.

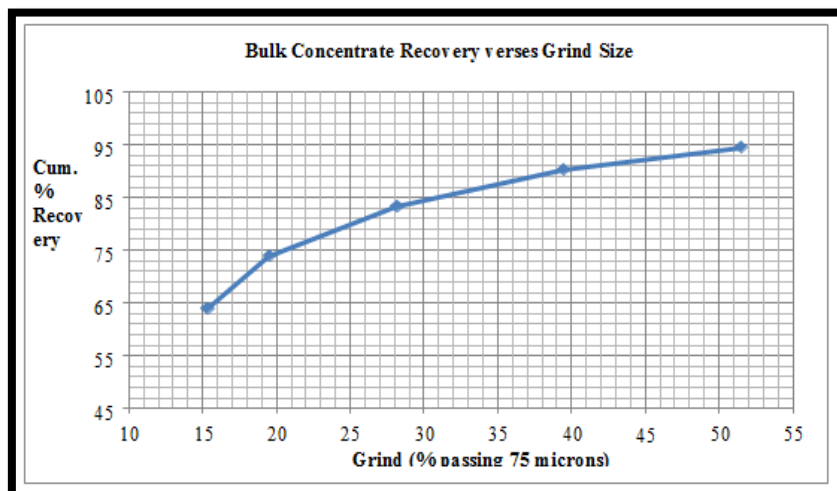
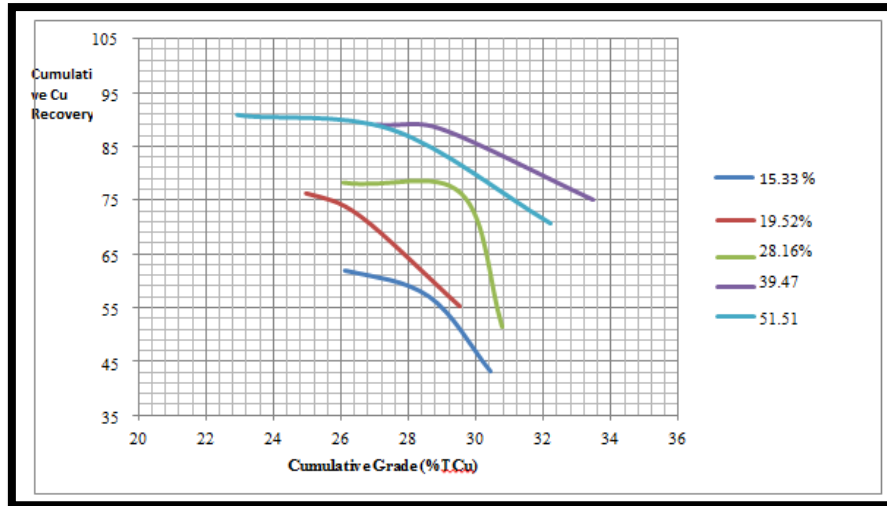


Figure 5: Bulk concentrate recovery versus grind size at %percent passing 75microns



**Figure 6:** Recovery of minerals against grade at different grind

The profile in figure 6 shows that recovery of values and grade increase as the fineness of grind increases. It can further be observed that the higher the recovery the lower the grade and also, as the particles get finer, curves were pushed right or upwards, giving greater opportunities for recovery improvements to be made. The grade – recovery relationship at 39.47% and 51.51% passing 75 micron are somehow the same. However, the best results (grade and recovery) are obtained at 51.51% passing 75 micron.

On average, weight percent solid to concentrate and recovery at 15.33% passing 75 micron grind is the lowest (9.81% Wt. to concentrate and 64.575% recovery), and at 39.47% passing 75 micron grind is the highest (15.661% Wt.% to concentrate and 90.315% recovery). Recovery of 94.482% at 51.51% passing 75 micron grind is, however, obtained.

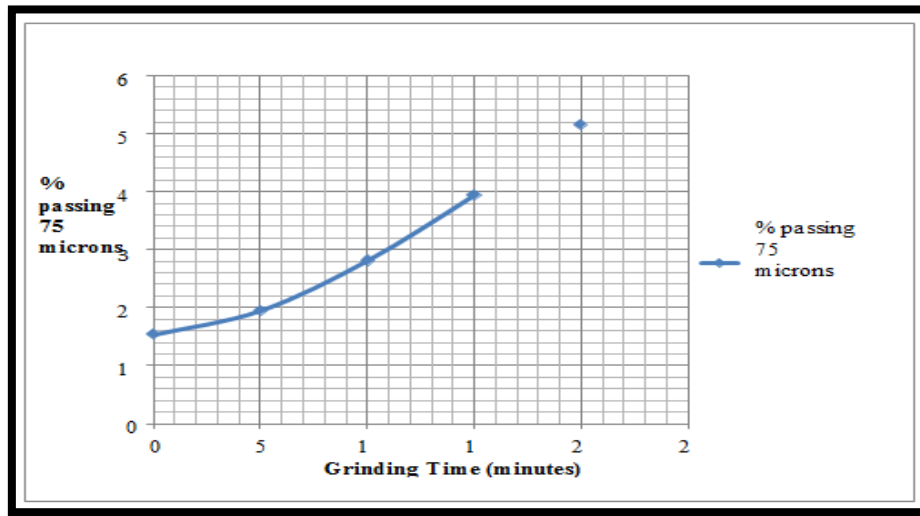
There was an improvement in the grade and weight to concentrate as the grind increased. The profiles at 39.47% passing 75microns and at 51.51% passing 75 microns are somehow the same. The highest grade and weight to concentrate are attained with 39.47% passing 75microns (grade of 33.479% TCu and cumulative wt. % to conc. 15.661%).

The effect of grind time on particle size can be observed in fig. 7. As grinding time increases the particles were getting finer i.e. (percentage of particles passing 75microns increases). The 20 minutes grinding time gave the finest grind (51.51%) followed by 15 minutes (39.47% grind), 10 minutes (28.16% grind), 5 minutes (19.52% grind) and 0 minute (15.33% grind), respectively passing 75microns sieve, which is a standard plant comparison sieve of measure.

The graphical depictions comparing the flotation kinetics for the ore at different grinds show that the recoveries of values improve with increasing the fineness of grind. The terminal recoveries are attained within three minutes of flotation time at most of the levels of grind. The flotation kinetics at 39.47% and 51.51% passing 75 micron are closely the same. The Same observation is made to flotation kinetics at 19.52% and 28.16% passing 75 microns. At about 2.5 minutes of flotation time the highest recoveries attained is 90% with 39.47% passing



75 micron. Increasing the fineness of grind to 51.51% passing 75 micron and flotation time resulted in marginal improvement of copper recoveries to 94.48%.



**Figure 7:** Interplay of grind time on particle size

The way to increase the mineral content in the concentrate depends on the particle grade. It is well known that individual particle grade is a function of its degree of liberation, and degree of liberation is dependent on the individual particle size.

The relationship between the grade and size is quite obvious in the fact that large particles have grades that tend to cluster around the average grade of the ore, while fine particles are expected to have more extreme grades, respectively, both on the gangue range and on the concentrate range. On the other hand, in the case of separation by flotation, the interactive behavior of particles due to their properties makes size become important in two different ways: a) it influences both the physics of separation, e.g. controlling the collision mechanisms between particles and bubbles, b) On the individual particle grade, it accounts for its control depending upon the degree of liberation.

*Recoveries of mineral values and grade increase as the grind gets finer. The increase in recoveries and grade is due to high liberation and decrease in mass of particles. However, increase in the recovery of values at a particular grind is coupled with decrease in the grade which is observed in fig. 6. For instance, the effect of grind on recoveries of values at a particular grade can be observed by considering the grade of %TCu 26 where recoveries at 15.33% passing 75micron recovery is 61.85%, at 19.52% passing 75micron recovery is 76.23%, at 28.16% passing 75micron recovery is 78.13%, at 39.57% passing 75 micron recover is 90.70% and at 51.51% passing 75micron recovery is 91.23.*

*However, the profile of 51.51% grind is not to the right of the profile of 39.47% grind. This can be due to fine particle entrainment. Fine, tiny particles also known as slimes, of non-sulphide copper and nature gangue report to concentrate and valuable sulphides are lost due to low floatability of the fine particles.*

#### **4. Conclusions**

The following conclusions have been drawn based on the analysis as follows;

- Increase in the fineness of grind result in increase in recoveries of values.
- Coarse grinding affects flotation recovery due to low liberation and the decreasing ability of the bubbles to lift the coarse particle.
- Increasing the recovery result in a reduction of the concentrate grade. The higher the recoveries of values the more gangue reports to the concentrate the lower the grade.

It is therefore recommended that fine particles be used in the production of concentrate for increased output.

#### **Acknowledgement**

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