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Research Article

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# Process for Concentration of Low Grade Copper Ore – A Process Design

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## Abstract
*The paper deals with the results of characterisation and flotation studies carried out on a low grade and complex copper ore sample with a view to design process for its concentration. Flotation studies were carried out under varying conditions of process parameters. Effects of granulometry of the feed, dosage of sodium iso-propyl xanthate as collector, pH and gangue depressant/dispersant were studied. Sulphidization technique and use of potassium octyl hydroxamate as auxiliary collector for flotation of oxidised minerals were observed to enhance copper recovery. Use of sodium silicate as depressant/dispersant for siliceous gangues helped in improving grade of copper concentrate. Rougher followed by multi-stage cleaning were found necessary to produce a high grade copper concentrate. Based on the studies undertaken the process was designed for concentration of the low grade copper ore sample.*

**Keywords:** Low Grade Copper Ore, Characterization, Flotation, Concentration, Process Design

## Introduction
Copper ore deposits are reported from igneous, sedimentary as well as metamorphic rocks. The ores generally occur as veins, disseminations and as bedded deposits. The principal copper bearing minerals are chalcopyrite, chalcocite, bornite (sulphides); malachite, azurite (carbonates) and cuprite (oxide). Native copper is also found. Generally, the run-of-mine copper ores contain low level of copper and for economic smelting ores are beneficiated to upgrade their copper content. Basically, sulphides are beneficiated by froth flotation technique using standard reagent like xanthate for flotation of copper sulphide minerals. The recovery of copper and the selectivity of separation are greatly influenced by the mineralogical characteristics of the ore and the various process parameters. In particular the factors like fine dissemination of minerals, association of gangue mineral slimes and the presence of oxidised copper minerals pose special problems in designing the flotation process and achieving the desired results [1-3]. The present paper deals with the results of characterisation and flotation studies carried out a low grade complex copper ore sample with a view to design process for its concentration to a product suitable for extraction of metal.

## Experimental
The copper ore sample used for the studies assayed 0.95% Cu with 80.46% $SiO_2$ and 9.55% $Al_2O_3$. Mineralogical and liberation characteristics of the sample are discussed in the subsequent section. Sodium iso-propyl xanthate (SIPX) from M/s Star Orechem International Pvt. Ltd., Nagpur was used as collector and methyl iso-butyl carbinol (MIBC) from M/s Viral Rasyan, Howrah was used as frother for flotation of copper bearing minerals from the sample. LR grade sodium hydroxide and sodium sulphide were used for maintaining pH of the pulp and for sulphidisation-flotation experiments respectively while commercial grade sodium silicate was used as depressant/dispersant for siliceous gangues. Potassium octyl hydroxame (KHXM) was synthesised in laboratory and was used as an auxiliary collector for enhancing flotation of oxidised copper minerals.

Polished sections of the copper ore sample were studied under reflected light optical microscope and different size fractions were investigated using a zoom stereomicroscope. Few polished sections were also studied under scanning electron microscope (SEM) with EDAX to confirm the composition of some mineral phases. Bench scale flotation experiments were carried out in a standard Wemco Fagergren Laboratory Flotation Cell. For this purpose, 0.5 kg of -1.68 mm crushed sample was wet ground in laboratory rod mill at 66% pulp density and floated after conditioning with flotation reagents, at a pulp density of 20%. To avoid dilution of reagents concentration, reagentised water was added to make up water level in flotation cell during the experiment. Timed floats were collected to obtain kinetic and equilibrium flotation data. All the products from flotation experiments were dewatered, analysed for copper and results were computed.

## Results & Discussion

### Mineralogical Characteristics

Mineralogical characterisation of the sample revealed that chalcopyrite was the major copper bearing mineral with pyrite as the major associate ore mineral. Other important copper bearing minerals observed were bornite and covellite. Traces of tetrahedrite, malachite and azurite were also recorded. The major gangue forming minerals were silicates and these mainly included quartz, feldspar, mica and some minerals from the pyroxene and amphibole groups. Iron oxide minerals such as magnetite, goethite and hematite and jarosite were also conspicuous.

Chalcopyrite and pyrite occur in wide size ranges varying from less than 10□m to ~3mm. Fine chalcopyrite crystallites were observed in inter-granular grain boundaries of silicates and very fine inclusions within quartz. Though some grains of the ore minerals were liberated at a coarser size fraction, in majority cases the liberation was effective below 105 or 74 microns. Observations on different size fractions under the stereomicroscope revealed that liberation of various minerals does not follow any particular pattern because of their irregular habit. This is also partly because of the intricate association of ore and gangue minerals having intergrowth, inclusion and exsolution type of texture. The interlocking is in very fine sizes and this necessitated fine grinding for liberating the ore minerals. Minerals such as bornite, covellite, goethite /jarosite were more concentrated in finer fractions. Photomicrographs showing typical features of the sample are shown in Figs. 1, 2.

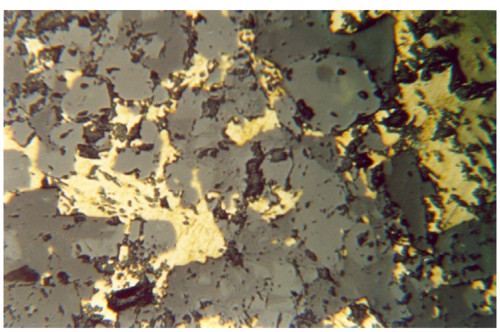

**Figure 1:** Chalcopyrite Occurring at Inter-Granular Grain Boundaries of the Silicates

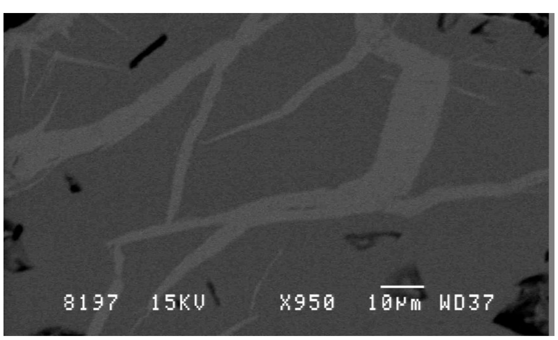


**Figure 2:** Back-Scattered Image of Bornite with Covellite Veins

## Flotation Studies

### Effects of Particle Size on Flotation Characteristics

Experiments were carried out to study the effects of particle size on floatability of copper bearing minerals. The results on particle size effects are shown in Fig. 3. As it is evident that due to better liberation of copper bearing minerals from gangues, with an increase in fineness of feed from 24.6% -74 micron to 66.5% -74 micron there is an improvement in copper recovery from 62.9 to 90.2% and an improvement in flotation kinetics was also observed. But further increase in fineness of feed did not show any favourable improvement rather flotation kinetics was affected and there is slight loss of copper recovery [4]. Low floatability with excessive fineness of feed could be due to reduced collision efficiency of particles with air bubbles. So, a flotation feed consisting of 66.5% particles below 74 microns was considered suitable for flotation of copper bearing minerals.

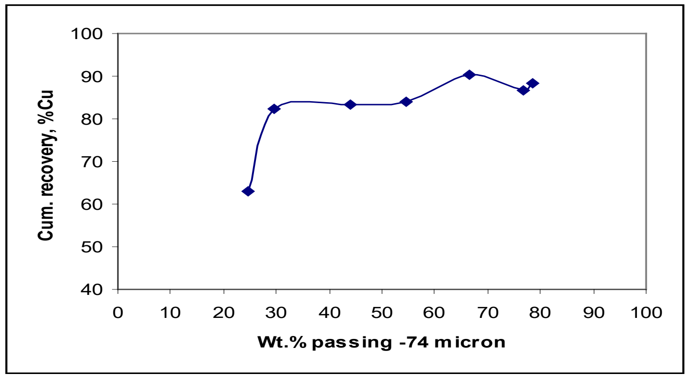


**Figure 3:** Effect of Particle Size on Copper Recovery

### Effects of Dosage of Collector

Collectors by their adsorption impart hydrophobicity to the mineral surface and hence enhance floatability of minerals. In order to study the effect of collector dosage on flotation of copper bearing minerals, experiments were carried out with varying dosages of xanthate. The flotation results are shown in Fig. 4. As it can be seen from the results that with an increase in xanthate dosage from 0.075 kg/t to 0.15 kg/t, there is a sharp increase in equilibrium copper recovery from 75% to 90.2%. But a further increase in collector dosages (0.3 kg/t and 0.6 kg/t) resulted in a decline in flotation recovery of copper values as well as flotation kinetics.

### Use of Gangue Depressant/Dispersant

Quartz and silicates were the major gangue forming minerals with the sample. Sodium silicate is widely used as depressant/dispersant for siliceous gangues. Experiments were carried out with varied dosages of sodium silicate for studying its effects on depression of quartz and silicates. The flotation results on the use of sodium silicate as the depressant for siliceous gangues are shown in Fig. 5. The flotation data reveal that the use of sodium silicate helps in improving selectivity of separation and improves concentrate grade. An increase in dosage of sodium silicate from 0 to 2 kg/t led to improvement in grade as well as flotation kinetics but with a lowering in recovery beyond 0.5 kg/t. However, use of further higher dosage of sodium silicate shows a decline in performance, which could be due to depressing effect of sodium silicate on copper bearing minerals with an excessive high dosage. So, a moderate dosage of 1-2 kg/t of sodium silicate is considered suitable for enhancing selectivity of copper flotation.

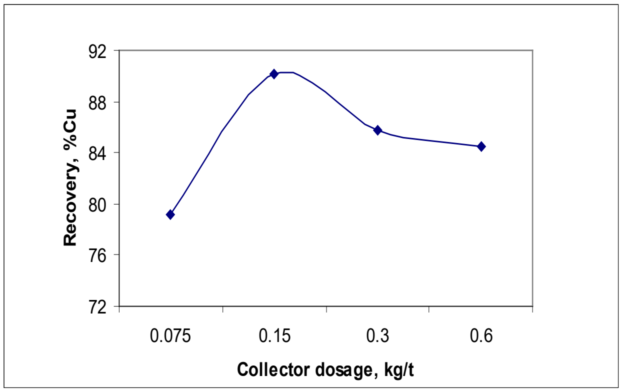


**Figure 4:** Flotation Results with Varying Dosage of Collector

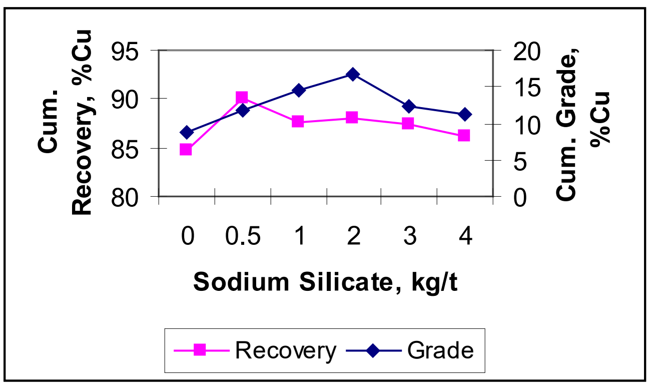


**Figure 5:** Effects of Sodium Silicate of Floatability of Copper Minerals

## Improving Copper Recovery

The maximum recovery obtained was 90.8%. Mineralogical chararacterisation of the sample indicated the presence of malachite and azurite - oxidised copper bearing minerals, in addition to copper sulphide minerals. Generally oxidised minerals poorly float with sulphydryl collectors [4]. Sulphidisation technique attempts to convert the surface of oxidised mineral to corresponding sulphide so that it becomes amenable to flotation by xanthate. Sulphidisation –flotation experiments were carried out using sodium sulphide as the sulphidising agent. The results with varied dosages of Na2S are shown in Fig. 6. Sulphidisation improved copper recovery as well as kinetics up to a certain dosage of sodium sulphide. At sodium sulphide dosage of 0.5 kg/t, equilibrium recovery is 94.2%. The improvement in copper recovery could be mainly due to enhanced recovery of oxidised minerals like malachite and azurite which are only a small fraction of the total copper bearing minerals in the feed. Higher dosage of sodium sulphide adversely affects copper recovery, because it's also acts as depressant for sulphide minerals.

Alternatively, use of potassium octyl hydroxamate as an auxiliary collector helped in improving copper recovery by 4%. Potassium octyl hydroxamate is a chelating type flotation collector which can interact with copper ions on the mineral surface, forming stable cooper and can float oxidised/oxide copper minerals.

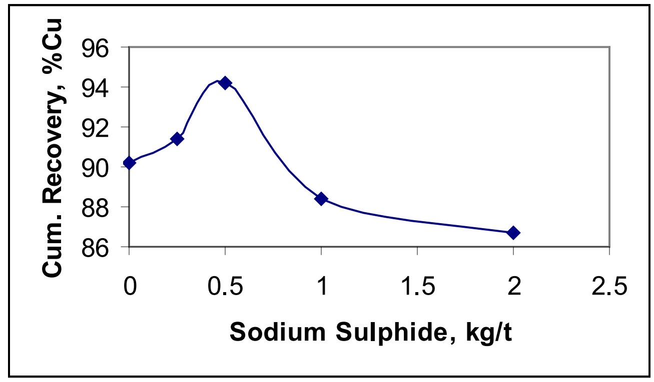


**Figure 6:** Effect of Sodium Sulphide on Copper Recovery

## Cleaning Flotation and Process Flow- Sheet

Having established the process conditions for rougher flotation, cleaning flotation experiments were carried out to improve quality of copper concentrate. Further the results of bench scale flotation studies were validated through large scale trials and process was designed for concentration of the copper ore sample. The results indicated that it was possible to obtain copper concentrate with 29.25% Cu with copper distribution of 81.7% by two stages of cleaning of rougher float. Third stage of cleaning flotation further enhanced concentrate grade to 31.77% Cu and 32.43 % Cu with 75.4% copper distribution respectively. The flow-sheet basically consists of two stages of crushing, wet grinding in closed circuit with classifier, conditioning of slurry with flotation reagents, rougher and three stages of cleaning flotation with intermediate conditioning with flotation reagents followed by dewatering to give final copper concentrate.

## Conclusions

The sample was of low grade with copper content of 0.95% with silica and alumina as the major impurities. The major copper bearing mineral was chalcopyrite followed by bornite and covellite with traces of tetrahedrite, malachite and azurite. The major gangues were quartz and silicates.

Presence of oxidised copper minerals and slimes affect flotation performance. Sulphidisation technique and use of potassium octyl hydroxamate found helpful in enhancing copper recovery. On the other hand, sodium silicate aided to flotation selectivity and improved concentrate grade.

Rougher followed by two stages of cleaning flotation resulted in copper concentrate assaying 29.25% Cu with 81.7% copper distribution. Third cleaning further improved grade to 31.77% Cu.

## Acknowledgements
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