

BENEFICIATION OF COPPER & NICKEL ORES

COPPER ores in India are of low grade like any other deposits elsewhere in the other parts of the world. Chalcopyrite is the most common and usual copper mineral; the other minerals have been chalcocite, covellite, bornite, which are all copper and copper-iron sulphides while enargite, tetrahedrite and tenantite are copper, antimony/arsenic sulphides. Apart from these, oxide and carbonate ores of copper such as cuprite, tenorite, malachite and azurite also occur in minor quantities. The copper minerals are concentrated by flotation process usually employing xanthates as collectors and pine oil as frother. Most of the deposits are of complex nature and needed complicated processes for their beneficiation.

Till recently there are no specific nickel ore deposits in India but the copper ores in Singhbhum Dist., of Bihar contain minor quantities of nickel contributed by the nickel sulphides like, millerite, violarite, pentlandite etc. These minerals are associated with either copper minerals or along with the other gangue present in the ore. Concentration of nickel sulphides alone was rather difficult due to their presence in minute quantity but were concentrated along with the copper minerals and the nickel was later recovered from the acid liquor after electrolytic refinement of copper. Two other nickeliferous ores not containing copper were investigated without success. Table 3.4, at the end of the chapter, summarizes the beneficiation results on various samples of copper and nickel ores.

A. NICKELIFEROUS LATERITE FROM SUKINDA/ORISSA

Recently vast deposits of low grade nickelifer-

ous laterite were discovered in Sukinda area of Cuttack dist., Orissa by G.S.I. The grade of the deposits is around 0.8% Ni and the deposits may run upto 14 million tonnes. A sample of nickeliferous laterite was received from the Director of GSI, Eastern Circle for beneficiation studies. The sample was ferruginous and clayey in nature and had the following analysis.

<i>Constituent</i>	<i>Assay%</i>
Ni	1.00
Cr ₂ O ₃	1.90
Fe ₂ O ₃	72.80
Mn	0.62
S	0.42
SiO ₂	4.98
Al ₂ O ₃	4.66
LOI	12.20
Cu & Co.	Trace

Microscopic examination had revealed the presence of goethite, hematite, chromite, ilmenite, quartz etc., but no specific nickel mineral was identified. Nickel might be present along with the iron minerals.

High intensity wet magnetic separation tests indicated that most of the nickel was lost in the slimes with a nominal recovery of 16.5% Ni in the magnetic concentrates. Reduction roast followed by magnetic separation indicated uniform nickel analysis in different magnetic and non-magnetic products. Tabling tests and flotation tests under different conditions and reagent combinations indicated the uniform distribution of Ni in various products. From the experimental results it was concluded that by conventional ore dressing methods, concentration of nickel minerals was impossible with this ore sample.

Based on the chemical methods like leaching of nickel recovery, a pilot plant is set up in NML for the treatment of Sukinda Nickel Ore.

B. NICKEL ORE FROM ASSAM

A nickeliferous serpentinite sample was received from the Director, G.S.I. Assam circle for beneficiation studies. The sample was pale green in colour with occasional metallic inclusions and was composed of fines and lumps upto 75 mm, with the following chemical analysis.

Constituent	Assay%
Ni	0.48
Fe	8.94
SiO ₂	37.00
Al ₂ O ₃	2.00
CaO	0.04
MgO	32.83
CO	0.05
S	0.146
LOI	14.10

Microscopic examination of the sample indicated the presence of magnetite which was partly oxidised to hematite in the sample, but no nickel mineral was found out.

Attempts were made employing magnetic separation both wet and dry, and also tabling at different sizes, but all the tests indicated that nickel content in the products obtained with different tests was alike. It was concluded from the tests, that recovery of Nickel by normal ore dressing methods was impossible and chemical methods may be successful.

C. COPPER ORES FROM BIHAR

Indian Copper Complex of Hindustan Copper Ltd., are working out the copper ore deposit in Mosabani and Surda areas and processing at their Maubhandar concentrator and smelter. In addition they have set up two more concentrators at Mosabani and Maubhandar. The copper ore contains appreciable amounts of nickel which is recovered finally as nickel sulphate after electrolytic refining of copper. Batch and pilot plant scale investigations have been conducted on the copper ores of Mosabani from various points of interest.

(i) Sample No. 1

The investigation was sponsored by M/s. I.C.C to find out a method for the better recovery of Nickel and also for the possibility of recovering the apatite which is being rejected at present. Tests were conducted initially on the present copper tailings which analysed as follows. Analysis of their ROM ore is also given for comparison.

Constituent	Tails sample	ROM Ore
Cu	0.07	2.2
Ni	0.073	0.0804
P ₂ O ₅	1.49	1.36
S	1.45	Not analysed

Chemical analysis of the various sized portions of the tailing indicated that the -100 mesh portion and finer portions contained almost 0.1% Ni with a total distribution of 77.2% Ni in the total -100 mesh portion. Magnetic separation and tabling tests with the tailing sample produced concentrates analysing respectively 0.166% Ni with 28.8% Ni distribution and 0.047% Ni with 17.6% Ni distribution in it.

Flotation tests with 0.1 kg/tonne of xanthate and 0.12 kg/tonne pine oil at a pH 5.5 with 24 mins of flotation time, produced a concentrate analysing 0.178% Ni with 26.6% Ni distribution. When the sample was ground 45% -200 mesh fineness, the concentrate obtained under optimum conditions analysed 0.224% Ni with 43.9% Ni distribution.

Another series of tests conducted with the run-of-mine ore indicated that under the optimum conditions of 44% -200 mesh ground, 1.3 kg/tonne of lime, 0.04 kg/tonne of xanthate and 0.04 kg/tonne of pine oil and 30 minutes of flotation time a combined Cu-Ni concentrate analysing 12.5% Cu, 0.31% Ni with Cu & Ni recoveries of the order of 96.5% and 65.6% respectively. Alternatively with a grind of 70% -200 mesh, with similar reagent additions and 4 minutes of flotation a combined Cu-Ni concentrate analysing 10.4% Cu with 91% distribution and 0.346% Ni with 73.2% Ni distribution may be produced. Thus it is concluded that the nickel recoveries from Mosabani copper ore may be improved either by giving 30 mts. total flotation (6 min for Cu & 24 mins for Ni) time with a feed ground to 44% -200 mesh or with a total 8 minutes (2 mts for Cu & 6 mts for Ni) flotation with 70% -200 mesh feed.

(ii) Sample No. 2

Batch and pilot plant scale tests were taken up on a 100 tonne run of mine copper ore received from I.C.C. The sample had the following analysis.

Constituent	Assay%
Cu	1.80
Ni	0.08
S	2.60
Fe	11.76
SiO ₂	72.29
Al ₂ O ₃	7.00
MgO	0.65
CaO	1.27
Mo & Co	Trace

Microscopic examination indicated the predominance of chalcopyrite amongst the sulphides followed by pyrite and pyrrhotite. Minor amounts of magnetite and hematite were also observed. Sulphides were liberated from the non-metallic gangue at 48 mesh size.

The investigation was sponsored by I.C.C. to compare the performance of the pneumatic cells against the Denver type cells, to improve the Ni & S recoveries, to compare the present flowsheet of I.C.C. with NML's flowsheet and to modify the I.C.C. flowsheet accordingly.

Batch tests indicated that, with a grind of 48.4% — 200 mesh, employing 0.03 kg/tonne of xanthate and 0.06 kg/tonne of pine oil a bulk rougher float analysing 20.8% Cu, 0.41% Ni and 26.3% S with respective recoveries of 96.4%, 43.0% and 85.5% was produced. When the rougher float was cleaned once, the concentrate analysed 22.6% Cu, 0.41% Ni & 28.5% S with respective distributions of 95.2%, 38.9% and 83.9%.

Instead, when the first rougher float was combined with the cleaner float obtained from 2nd & 3rd floats, the concentrate analysed 22.95% Cu with 95.5% Cu distribution and 0.42% Ni with 39.2% Ni distribution in it. If the floats 2 & 3 were ground to 90% — 100 mesh size and cleaned, the combined concentrate analysed 23.2% Cu with 95.3% recovery, 0.45% Ni with 37.7% recovery and 26.7% S with 80.6% S recovery in it.

Tabling tests with the flotation tests did not help

in the increase of recovery but regrinding and flotation of the tails has increased Ni recovery by additional 5%. Tests at elevated temperature — after removing the rougher concentrate (3 floats) had yielded a further recovery of 3.9%. Complete flotation test under optimum conditions at elevated temp. with a little extra flotation time produced a concentrate analysing 18.7% Cu, 0.407% Ni with 97.0% Cu & 54.8% Ni recoveries in it.

Pilot Plant Studies

Pilot Plant studies were conducted on a 100 tonnes sample received from Hindustan Copper Ltd., (I.C.C.), Ghatsila. The ore sample was crushed to 13 mm at the mine head and sent for testing. The crushed ore from the bin was fed into a 183 cm × 91.5 cm ball mill operating in closed circuit with a rake classifier.

Run No. 1. The classifier over-flow was conditioned with xanthate and pine oil and then sent to flotation cells. The flotation was conducted in a battery of 8 nos. of Denver No. 8 sub. A flotation cells (2.75 cft). The tailings were scavenged in a similar set of 4 cells and another set of 6 cells of Denver No 7 Sub-A cells; the scavenger concentrate was re-circulated to the main stream. This flowsheet was similar to that of I.C.C. plant at Ghatsila except that mechanically agitated cells were used in place of pneumatic cells. It was observed that by using mechanically agitated cells, the total flotation time for the bulk sulphide flotation dropped from 27 mts (pneumatic cells) to 16 mts. Feed rate was also varied from 500 kg/hr to 900 kg/hr for the same flotation time. The concentrate analysis varied from 20.0% Cu with 96.7% Cu distribution to 25.2% Cu with 96.6% Cu distribution respectively.

Run No. 2. In this test the primary flotation time was increased by introducing more cells and the scavenger concentrate was sent to the ball mill for regrinding. The primary concentrate was cleaned in 3 Nos of Denver No. 7 Sub-A cells. The total flotation time in this test was 30 mts. The concentrate obtained during this run analysed 20.71% Cu, and 0.497% Ni with 96.6% Cu and 52.2% Ni distribution in it.

Run No. 3. In this case the flowsheet of Run No. 1 was adopted but with a slightly coarser grind i.e. 43 to 44% — 200 mesh feed instead of

46 to 48% -200 mesh grind. The final concentrate of this test analysed 24.4% Cu and 0.45% Ni with 95.6% Cu and 39.7% Ni distributions in it. The copper and Ni grades are comparable to Run No. 1. but the recovery of Ni was poorer in this case.

Run No. 4. This test was similar to Run No. 2 except that 40% -200 mesh grind was used and additional quantity of collector was added to the scavenger cells. The concentrate analysed 21.8% Cu and 0.45% Ni with 95.1% Cu and 44.2% Ni distributions in it.

Copper Ores from Rakha Mines

Three different samples were received, one for batch scale tests and the other two for pilot plant scale tests. The ore from Rakha Mines contained molybdenite also in addition to nickel and the recovery of molybdenite has been mentioned elsewhere in the report.

(i) Sample No. 1

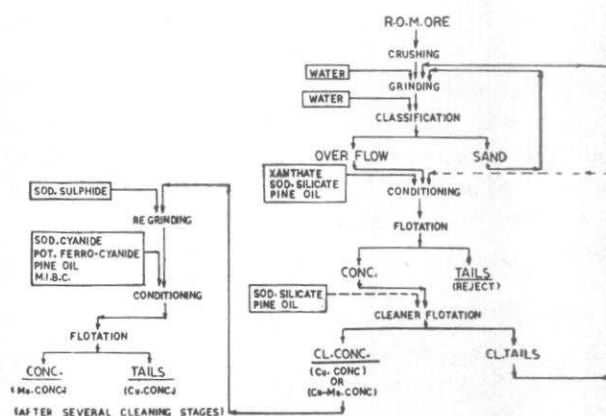
This sample was received in the early stages of work on Rakha Copper Ore through M/s. NMDC Ltd. The sample was composed of fines and lumps upto 150 mm and analysed as follows :

Constituent	Assay%
Cu	2.73
Fe	5.54
S	3.96
SiO ₂	73.08
Al ₂ O ₃	10.14
MgO	0.60
CaO	1.00
CO	0.02
Ni	0.072
Mo	0.025
Au	0.2 dwt/ton
Ag	2.2 dwt/ton
P ₂ O ₅	0.78
U ₃ O ₈ (Equi)	0.030
AS, Sb, Mn, Pb,	
Bi & Cr	Trace
Te	Nil

Microscopic examination has revealed that chalcopyrite was the chief copper mineral, the other metallic minerals being covellite, vallerite, cubanite, violarite, molybdenite, linnaeite, and

traces of pyrrargyrite, bitelluride and sylvanite. Chalcopyrite was liberated from the gangue at about 100 mesh size but molybdenite and chalcopyrite were free at 400 mesh size only.

A series of batch tests conducted for determining the optimum conditions indicated that a grind passing 54.8% through 200 mesh screen, with 0.8 kg/tonne of lime to adjust the pH of the pulp to 8.8, 0.021 kg/tonne of xanthate and 0.03 kg/tonne of pine oil were optimum where in a copper concentrate assaying 24.25% Cu with



Flowsheet 3.2—General flowsheet for beneficiation of copper ores (1) molybdenum sulphides

97.6% recovery was produced. Use of higher xanthates had slight improvement on the recovery. However, regrinding of the rougher concentrate and cleaning for the recovery of molybdenite had improved the grade of copper to 29.2% Cu with 82.2% Cu recovery in it. And the recirculation of the cleaner tails would further improve the recovery of copper.

(ii) Sample No. 2

100 tonnes run of mine ore were received from M/s. Hindusthan Copper Ltd. to undertake comprehensive batch and pilot plant scale investigations in order to recover copper, molybdenum and nickel minerals and also to provide flowsheet and other necessary data for the setting up of a concentrate plant. The run of mine sample analysed as follows :

Constituent	Assay%
Cu	1.34
Fe	10.14
S	2.03
SiO ₂	65.80
Al ₂ O ₃	10.58
MgO	2.94
CaO	0.66
Ni	0.053
Mo	0.016
U ₃ O ₈ (Equiv)	0.011
P ₂ O ₅	Trace

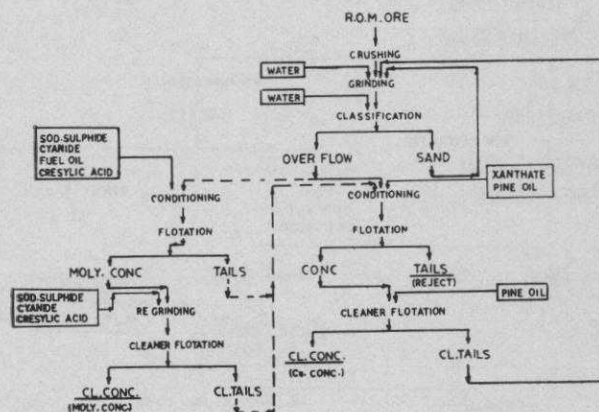
Microscopic examination revealed that chalcopyrite, violarite and molybdenite were the chief copper, nickel and molybdenum contributing minerals respectively. Copper minerals were liberated at 100 mesh and the moly-minerals at 200 mesh size. Nickel mineral was found to be very closely associated with copper & non-metallic gangue minerals.

Batch flotation tests conducted prior to the pilot plant tests indicated that under the optimum conditions of 0.06 kg/tonne xanthate, 0.09 kg/tonne pine oil and 1.6 kg/tonne of lime with a feed-ground to 60% -200 mesh and 30 mts. flotation time a bulk concentrate analysing 13.25% Cu, 0.150 Mo and 0.308% Ni with 95.7% Cu and 58.6% Ni recoveries was produced. But the separation of molybdenite from the bulk concentrate was found to be difficult and hence selective flotation of molybdenite followed by copper and nickel minerals was adopted to. Recovery of nickel beyond 58.6% was not successful.

Batch differential flotation studies for the concentration of molybdenite followed by copper and nickel sulphides indicated that under the optimum conditions of 66% -200 mesh grind, 0.1 kg/ton of sod. cyanide, 0.16 kg/tonne of fuel oil, and 0.03 kg/tonne of cresylic acid produced a rougher moly. conc. analysing 18.2% Cu, 0.178% Ni and 1.24% Mo with 16% Cu and 3.7% Ni recoveries in it. Then the rougher moly. tails were further floated with 0.12 kg/tonne xanthate, 0.09 kg/tonne of pine oil and 1.6 kg/tonne of lime to produce a rougher Cu, Ni concentrate analysing 16.5% Cu, 0.234% Ni and 0.024% Mo.

The rougher moly. concentrate on repeated cleaning using sodium silicate and sod. cyanide

to produce a moly. float simultaneously produced Cu-Ni tails. This when combined with the cleaner Cu-Ni flotation concentrate obtained from the cleaning of rougher concentrate, analysed 22.07% Cu with 87.4% recovery and 0.28% Ni with 25.3% recovery. It was found during the tests that long flotation time was necessary to get the maximum recovery of nickel minerals.



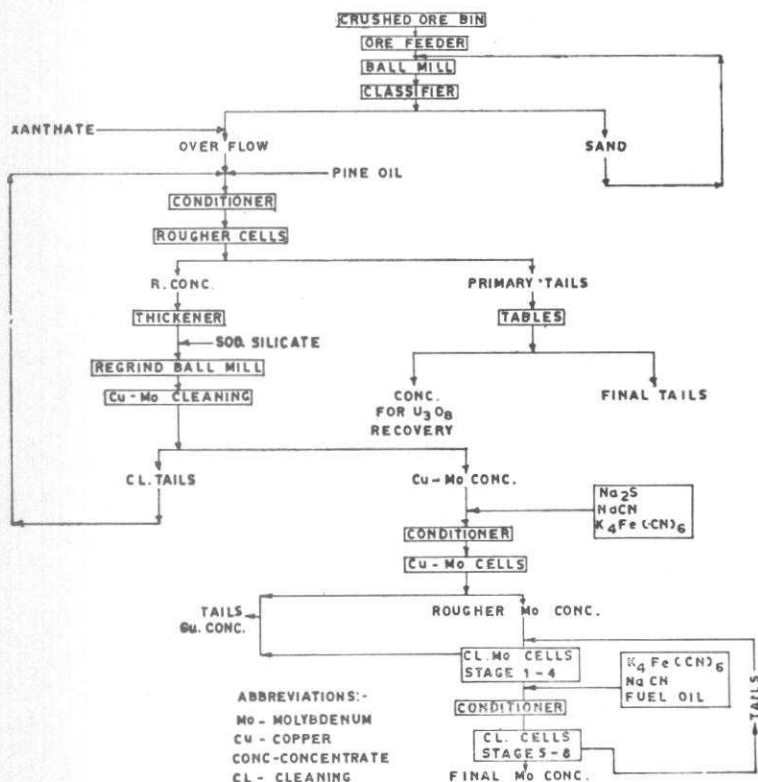
Flowsheet 3.3—General flowsheet for beneficiation of copper ores (2) containing molybdenum sulphide

Pilot Plant Tests

Continuous pilot plant tests were conducted with 300 tonnes bulk Rakha Copper Ore. The ore after hand cobbing the larger pebbles was crushed to 9.5 mm in a jaw crusher followed by a cone-crusher operating in closed circuit with a vibrating screen and stored in the bin. The crushed ore from the bin was fed through a constant weight feedometer to a ball mill working in closed circuit with rake classifier.

Lime to adjust pH to 7.0–7.5, sodium cyanide to depress copper sulphides and fuel oil as collector for molybdenite were added into the ball mill. The classifier overflow was conditioned with cresylic acid and then treated in a battery of 6 nos. of Denver No. 8 (2.5 cu-ft) Sub-A cells to collect the rougher molybdenite concentrate. The tailings were conditioned again with xanthate and pine oil and floated in a battery of 8 nos. of Denver No. 8 (2.5 cuft) and 6 nos. of Denver No. 7 (1.5 cuft) to produce a rougher copper-nickel concentrate, which was cleaned once in one Denver No. 8. Sub-A flotation cell. The cleaner tails were recirculated to the copper roughing circuit.

The final copper-nickel concentrate obtained analysed 20.07% Cu, and 0.26% Ni with 93.94% Cu and 30.8% Ni distributions in it.



Flowsheet 3.4—Beneficiation of copper ore for Rakha mines

Alternatively bulk sulphide flotation followed by selective flotation to separate molybdenum from copper and Ni sulphides was also tried. The classifier over-flow was conditioned with xanthate and pine oil and was treated in bank of 14 Nos Denver No. 8 Sub-A cells and 6 Nos of Denver No. 7 Sub-A cells thereby providing a total flotation of about 30 mts. The bulk concentrate analysed 20.5% Cu, 0.347% Ni and 0.237% Mo with respective distributions of 94.5%, 40.4% and 91.7%. However, due to the practical difficulties to separate the moly. & Cu-Ni minerals, this method was not recommended.

(iii) Sample No. 3

A 100 tonne representative run of mine ore sample was received from M/s. HCL for the beneficiation studies on a pilot plant scale. The present sample would be the type feed for the phase-II development programme of the Rakha Copper concentrator plant. The sample consisted of 100 mm lumps down to fines and analysed as follows:

Constituent	Assay%
Cu	0.92
Ni	0.025
Mo	0.015
Fe	9.50
S	1.35
SiO ₂	62.25
Al ₂ O ₃	7.90
MgO	2.36
CaO	2.50
UO ₂ (Equiv)	0.013
P ₂ O ₅	0.95

Mineralogical examination indicated that chalcocopyrite was the chief copper mineral found in association with molybdenite, pentlandite, pyrite, pyrrhotite and magnetite. Quartz, chlorite, mica and tourmaline were the non-metallic gangue. Chalcocopyrite was liberated from the metallics at 100 mesh size and the non-metallics at 65 mesh size. Pentlandite, molybdenite and violarite were liberated at 200 mesh size.

Batch tests indicated that under the optimum conditions of 54% -200 mesh grind, 0.03 kg/tonne of 1:1 mixture of pot. ethyl and pot. isopropyl xanthate and 0.04 kg/tonne of pine oil at natural pH, a bulk sulphide concentrate analysing 16.0% Cu, with 94.5% recovery, 0.32% Ni with 60.0% recovery and 0.254% Mo with 90% Mo recovery was produced.

The rougher concentrate after regrinding to 82% -200 mesh with 0.5 kg/tonne of sod. cyanide, 0.25 kg/tonne of sod. sulphide, 0.25 kg/tonne of pot. Fe. cyanide and 0.08 kg/tonne of fuel oil with ten cleanings, a moly. float assaying 38.2% Mo and 1.13% Cu was produced while a Cu-Ni concentrate present as the moly. cleaner tails analysing 25.5% Cu with 87.38% recovery and 0.28% Ni with 31.0% Ni recovery was produced. However, the recovery of Cu-Ni & Mo have improved in the continuous pilot plant scale tests.

Pilot Plant Studies

The ROM ore was crushed in a primary jaw crusher set to 40 mm and then in a cone crusher set to 9 mm and operating in closed circuit with 9.5 mm vibrating screen. The fine ore crushed to 9.5 mm was stored in a bin and fed through a constant weight feedometer into a 183 cm × 91.5 cm ball mill operating with a rake classifier in closed circuit.

Xanthates were added to the classifier overflow and after conditioning, pine oil was added and then treated in a 2 Nos. of 2 Cu ft. Denver type flotation cell (Mfd. by Kedar & Co. Ltd. Cal.) where in a bulk sulphide concentrate was produced. The tailings were further treated on shaking tables for the recovery of uranium minerals.

The rougher bulk sulphide concentrate was thickened to 50% solids and then reground in a ball mill with sod. silicate and pine oil and treated in a battery of 4 Nos. of Denver No. 8 (2.5 Cu ft.) Sub-A cells to produce cleaner bulk concentrate. This was further conditioned with sodium sulphide, Pot. Ferrocyanide and sod. cyanide and then treated in a battery of 8 Nos. of Denver No. 8 Sub-A (2.5 Cu ft.) flotation cells wherein a rougher molybdenum concentrate and a copper tailing was produced. The rougher molybdenum concentrate was further cleaned for 8 times adding small amounts of sod. sulphide, sod. cyanide and pot. ferrocyanide to all the cleaner stages. The tailings of the 1st to 4th cleaner stages analysed 28 to 29% Cu and 0.05 to 0.1% Mo and hence combined with the copper concentrates. The cleaner tails from 5th to 8th stages was recirculated to the 1st molybdenum cleaner circuit. The copper concentrate obtained in the pilot plant runs analysed 25.4% Cu and 0.26% Ni with 91.6% Cu and 33.1% Ni distributions in it. The molybdenum concentrate analysed 41.8% Mo with 61.6% Mo distribution.

Jaduguda Uranium Ores

Uranium ores of Jaduguda contain appreciable amounts of Cu, Mo & Ni and at the instance of the UCIL, comprehensive batch and pilot plant scale investigations were taken up for the concentration of Cu, Mo & Ni minerals. Altogether four different samples were received for the concentration of molybdenite, copper and nickel sulphides, three samples on pilot plant scale and one on bench scale.

Sample No. 1

The sample analysed as follows :

<i>Constituent</i>	<i>Assay%</i>
Cu	0.17
Ni	0.17
Mo	0.032

The analysis indicated the copper content was lower than the copper ores of Mosabani area. Mineralogical examination of the sample indicated that chalcopyrite, pyrite, millerite, pentlandite, violarite, molybdenite, magnetite, and ilmenite formed the metallic minerals. Nickel minerals were found associated with copper minerals and molybdenite with the non-metallics.

A bulk sulphide concentrate assaying 0.94% Cu, 1.84% Ni and 0.50% Mo with their respective recoveries of 32.6%, 63.8% and 92.2% under optimum conditions of 0.05 kg/tonne of xanthate, 0.04 kg/tonne of pine oil employing a feed ground to 55% -200 mesh size.

Sample No. 2

The sample analysed as follows :

<i>Constituent</i>	<i>Assay%</i>
Cu	0.24
Ni	0.28
Mo	0.032

This sample was relatively richer in Cu and Ni contents. Under the optimum conditions mentioned above, a large quantity of bulk concentrate produced in the pilot plant investigation was supplied to UCIL and it analysed 1.16% Cu, 1.72% Ni and 0.28% Mo with recoveries of 55.1% Cu, 70.0% Ni and 99.8% Mo respectively.

Sample No. 3

The sample was prepared by blending of three different samples received from UCIL and the test sample analysed as follows :

<i>Constituent</i>	<i>Assay%</i>
Cu	0.180
Ni	0.200
Mo	0.036
Fe	7.440

Chalcopyrite, pyrite, millerite, pentlandite, violarite were the metallic sulphides found in the non-metallic gangue matrix. The sulphides were liberated at 400 mesh size.

Under the optimum conditions of 55% -200 mesh grind with 0.05 kg/tonne of xanthate, 0.04 kg/tonne of pine oil and 25 mts. flotation time a bulk sulphide concentrate analysing 1.7%

Cu with 35.7% recovery, 3.0% Ni with 57.1% Ni recovery and 0.77% Mo with 82.6% Mo recovery was produced. Differential flotation of molybdenite after regrinding the bulk sulphide concentrate to 100% -200 mesh, followed by steaming and three cleanings, a cleaner moly. tails i.e. Cu-Ni concentrate analysing 1.7% Cu and 3.0% Ni was produced with 35.6% Cu & 57.0% Ni recovery in it.

Selective flotation tests by floating of molybdenite first with 0.1 kg/tonne sod. cyanide, 0.5 kg/tonne fuel oil, and 0.026 kg/tonne cresylic acid, followed by xanthate flotation with 0.05 kg/tonne of xanthate and 0.04 kg/tonne of pine oil with 24 mts. flotation time, a Cu-Ni concentrate assaying 0.42% Cu with 7.1% Cu recovery, and 1.27% Ni with 19.6% Ni recovery was produced. When the cleaner moly. tails containing Cu & Ni sulphides was combined with the Cu-Ni conc., the product analysed 1.92% Cu with 41.8% recovery and 3.35% Ni with 65.8% recovery in it.

Further attempts to improve the grade of Cu-Ni concentrate were not fruitful due to very fine dissemination of the same in the non-metallics.

Sample No. 4

The sample was for pilot plant scale investigation for the recovery of Cu, Ni & Mo minerals. The ore analysed as follows :

Constituent	Assay%
Cu	0.14
Ni	0.17
Mo	0.021
SiO ₂	68.32
Fe	7.41

Rougher molybdenum concentrate was collected with 65% -200 mesh grind using fuel oil and cresylic acid which was later cleaned with sodium cyanide for the separation of Mo minerals from those of Cu-Ni. The rougher moly. tails were further floated with xanthates for the separation of Cu & Ni minerals. The combined Cu-Ni concentrate obtained from Mo cleaner circuit and cleaner Cu-Ni concentrate obtained from xanthate flotation analysed 1.16% Cu and 1.57% Ni with 28.3% Cu and 31.6% Ni recoveries in it.

In general it may be observed that the uranium ore from Jaduguda contained low copper which was difficult to concentrate to the smelter's speci-

fication. Nickel content was higher than that of Rakha Mines. Copper ores yielding fairly good recoveries warrant special attention of the same from the low nickel resources point of view in the country.

Chapri Copper Ore

The sample was received from M/s. Indian Copper Complex of H.C. Ltd. The sample consisted of 50 mm lumps to fines ; complete chemical analysis of the sample was as follows :

Constituent	Assay%
Cu	0.48
Ni	Trace
Fe	8.51
S	1.84
SiO ₂	69.40
Al ₂ O ₃	8.44
CaO	0.50
MgO	2.52
Mo & Co	Trace

Mineralogical studies of the sample indicated the presence of chalcopyrite in association with magnetite, pyrite and minor amounts of pyrrhotite. The non-metallic gangue was constituted by biotite, chlorite and quartz.

Flotation tests conducted under the optimum conditions of 48% -200 mesh grind employing 0.03 kg/tonne of Potassium Ethyl Xanthate and 0.04 kg/tonne of pine oil yielded a concentrate assaying 8.6% Cu with 92.4% Cu distribution in it. After 2 cleanings, the grade of the concentrate improved to 22.6% Cu with 88.6% Cu distribution. Copper recoveries are expected to improve in the continuous flotation operation when the middlings will be recirculated.

D. COPPER ORES FROM ANDHRA PRADESH

Low grade copper and lead ores are located and being developed in the Agnigundala area of Guntur Dist. in Andhra Pradesh. The copper ore samples were received from the Director, G.S.I. Southern Circle, Hyderabad for the beneficiation studies.

Sample No. 1

The sample was drawn from the Nallakonda block-Agnigundala area. The sample was prepared from the drilling cores and was composed

of lumps in size from 25 to 75 mm and had the following chemical analysis :

Constituent	Assay%
Cu	0.92
Pb, Zn & Ni	Trace
S	0.65
Fe	2.78
SiO ₂	72.44
Al ₂ O ₃	3.36
Co	0.07
MgO	3.54
Ag	16.00 gm/ton

Mineralogical examination of the sample revealed that chalcopyrite and bornite were the chief copper bearing sulphides followed by minor amounts of pyrite and sphalerite. Quartz followed by feldspars, carbonates, micas etc. formed the non-metallic gangue.

Tests indicated that with a grind 56% -200 mesh, employing 0.05 kg/tonne pot. ethyl. xanthate and 0.024 kg/tonne of pine oil at natural pH a copper concentrate analysing 21.3% Cu with 94% Cu recovery was produced. Test at still higher pH and higher xanthates did not show any improvement. The concentrate obtained under optimum conditions mentioned above, after one cleaning produced a concentrate analysing 26.6% Cu with 88.9% Cu recovery in it. In addition the concentrate analysed 300 gm/tonne of Ag and 0.012% Co.

Sample No. 2

The sample was drawn from Dhukonda block of Agnigundala area and analysed as follows :

Constituent	Assay%
Cu	1.24
SiO ₂	68.23
S	1.34
Fe	2.70
CaO	5.95
MgO	3.87
Zn, Co, Pb,	
Au, & Ni	Trace
Ag	0.6 gm/ tonne

Examination of the sample under microscope revealed that chalcopyrite was the chief copper mineral followed by minor amounts of chalcocite

and bornite. Traces of sphalerite and pyrite were also observed. Quartz, dolomite, and feldspars formed the bulk of the non-metallic gangue. Copper minerals were fairly liberated at 100 mesh size.

Tabling tests with 65 mesh feed produced a concentrate analysing 9.2 (conc+ Middling) with 60% Cu distribution in it. Flotation tests under optimum conditions of feed ground to 51.3% -200 mesh, 0.02 kg/ton of pot. ethyl. xanthate and 0.024 kg/tonne of pine oil, produced a rougher concentrate analysing 17.88% Cu with 93.7% Cu recovery in it. Attempts to recover more copper from the rougher tails after regrinding were not successful. Higher xanthates also did not improve the recoveries of copper. After one cleaning of the rougher concentrate, the product analysed 24.42% Cu with 92.0% Cu recovery and also analysing 0.017% Co and 9 gms/ton of Ag.

E. COPPER ORES FROM RAJASTHAN

Huge deposits of copper ores have been located and are presently being worked out by Hindusthan Copper Ltd. at Khetri, in Jhunjunu Dist., Rajasthan. In addition some more copper deposits and copper-lead-zinc deposits have been located at Bhagoni, Dariba-Rajapura and Balaria areas.

(i) Bhagoni Copper Ore

A sample of low grade copper ore from Bhagoni area in Alwar Dist. of Rajasthan was received from GSI. The sample was composed of fines and lumps upto 19 mm and analysed as follows :—

Constituent	Assay %
Cu	1.16
S	1.51
Fe	7.26
SiO ₂	23.58
Al ₂ O ₃	4.40
MgO	14.34
CaO	16.45
LOI	27.80
Ag	Trace
Au	Not present

Microscopic examination indicated that chalcopyrite was the only copper mineral found in

association with pyrite and pyrrhotite in the calc. granulite schist rock. Chalcopyrite was liberated at 65 mesh size. The non-metallic gangue minerals comprised of calcite, dolomite, epidote and amphiboles.

Preconcentration tests employing heavy media separation and jigging were done without success. Flotation tests conducted under the optimum conditions of 50% -200 mesh grind, 0.04 kg/tonne of pot. eth. xanthate and 0.05 kg/tonne of pine oil at natural pH produced a concentrate analysing 18.97% Cu with 93.4% Cu recovery. After one cleaning, the concentrate analysed 22.3% Cu with 86.7% Cu recovery. When the cleaner tails were reground and floated, a refloat concentrate assaying 15.0% Cu was produced with an additional recovery of 5.3% Cu. When the cleaner and recleaner concentrates were combined, the product analysed 21.6% Cu with 92.0% Cu recovery. Tests with higher xanthates and reground primary tails did not show any improvement on the copper recoveries.

Fatty acid flotation tests followed by two cleanings conducted with the rougher copper tails produced a calcite-dolomite concentrate analysing 30.52% CaO with 47.1% recovery and 20.28% MgO with 36.8% recovery in it.

(ii) Kolihan Copper Ore

M/s. NMDC Ltd. sent a 4 tonne lot copper ore composed of 75 mm to 0.5 mm lumps and fines for beneficiation studies at N.M.L. The sample analysed as follows :

Constituent	Assay %
Cu	2.69
Fe	15.57
Fe ₂ O ₃	22.26
S	8.18
SiO ₂	50.18
Al ₂ O ₃	8.87
CaO	0.69
MgO	0.98
LOI	4.98
Ag	2.6 dwt/tonne
Au	0.19 " "

Mineralogical examination revealed that chalcopyrite was the copper mineral and associated

with an equal quantity of pyrrhotite. Minor amounts of magnetite and pyrite were also present. Non-metallic gangue was composed of quartz, chlorite, ferromagnesian minerals, biotite etc. Chalcopyrite was liberated at 150 mesh size.

Batch tests indicated that with a grind of 52.2% -200 mesh, employing 2.5 kg/tonne of lime, 0.07 kg/tonne of xanthate and 0.01 kg/tonne of pine oil were optimum to produce a rougher concentrate analysing 16.6% Cu with 87.4% Cu recovery. After one cleaning the concentrate analysed 27.41% Cu with 93.8% Cu recovery in it.

Tests conducted with the cleaner and rougher copper tails to concentrate the iron sulphides employing 3 kg/tonne of sulphuric acid and an additional quantity of 0.06 kg/tonne of xanthate and 0.01 kg/ton of pine oil after one cleaning produced a pyrite-pyrrhotite concentrate assaying 0.88% Cu and 38.00% S (grade acceptable to industry) with 40.4% S recovery.

(iii) Copper Ore from Khetri

A sample of low grade copper ore composed of lumps upto 125 mm was received from M/s. NMDC, Ltd., for batch and pilot plant scale studies at NML. The sample analysed as follows :

Constituent	Assay %
Cu	0.80
Fe	18.63
S	3.08
SiO ₂	54.65
Al ₂ O ₃	9.62
MgO	4.54
LOI	3.67
Mo & As	Nil
Ni, Co, Ti & Se	Trace
Au	0.13 dwt/ton.
Ag	2.37 dwt/ton.

Microscopic examination revealed that chalcopyrite was associated with pyrrhotite, magnetite and pyrite. The non-metallic gangue was composed of quartz, chlorite, garnet, biotite etc. The metallics were liberated from the gangue at 65 mesh size and chalcopyrite from the rest at 150 mesh size.



Fig. 3.8 Flame like aggregates of violarite (white) in Pyrrhotite (grey). Etched with KOH. X 168. Copper ore (Khetri, Rajasthan).

The optimum conditions for the recovery of copper minerals was found to be a feed ground to 62.5 to 73.3% -200 mesh, 3.0 kg/tonne lime, 0.05 kg/tonne of xanthate and 0.05 kg/tonne of pine oil. The rougher concentrate obtained under the conditions analysed 9.52% Cu, with 87.4% Cu recovery. Use of higher xanthates had slightly reduced the tailing losses. The rougher concentrate after two cleanings in the alkaline circuit with higher xanthates analysed 24.80% Cu with 82.7% Cu recovery in it.

Flotation tests with the rougher tails in acid circuit produced a pyrite-pyrrhotite concentrate analysing 36.25% S with 29.0% S recovery.

Pilot Plant Studies

Pilot Plant tests were conducted on a 20 tonne bulk sample. The ore was stage crushed in jaw crusher and roll crusher to 7 mesh size and stored in a bin. The ore along with lime from the bin was fed to a 400 mm × 800 mm ball-rod mill operating in closed circuit with a spiral classifier. The classifier overflow was diluted to 28% solids and conditioned with xanthate and was treated in a battery of 6 Nos. of 1.5 Cu ft. Denver Sub-A cells and the tails were rejected. The rougher concentrate was cleaned twice in 3 cell batteries of same type and the final concentrate was thickened and filtered. The recleaner tails were recirculated to the ball mill for regrinding and treatment.

The concentrate obtained in the pilot plant run analysed 27% Cu with 82% Cu distribution in it.

(iv) Copper Ore from Khetri—Shaft No. 3

The sample analysed as follows :

Constituent	Assay %
Cu	0.79
Fe	20.16
S	2.85
SiO ₂	52.82
Al ₂ O ₃	10.20
CaO	Trace
MgO	5.09
Au	0.08 dwt/tonne
Ag	1.70 " "

Chalcopyrite was the copper mineral. The other metallic minerals were magnetite, pyrite and pyrrhotite. Quartz and chlorite followed by minor amounts of ferro-magnesian minerals and biotite formed the non-metallic gangue. Chalcopyrite was fairly liberated below 150 mesh size.

Flotation tests conducted under optimum conditions of 69.5% -200 mesh grind at pH 7.5, 0.05 kg/tonne of xanthate and 0.04 kg/tonne of pine oil produced a rougher copper concentrate analysing 3.36% Cu with 95.6% Cu recovery in it. Addition of copper sulphate during rougher flotation did not show any improvement; with three cleanings at pH 10.5, the concentrate analysed 24.33% Cu with 75.7% Cu distribution in it. Regrinding of the rougher concentrate before cleaning did not improve the values of grade and recovery.

Attempts to produce pyrite-pyrrhotite concentrate from the rougher copper tails did not produce a satisfactory grade of sulphide concentrate due to the sluggish flotation of pyrrhotite.

(v) Copper ore from Ghatiwalli Adit—Khetri

The sample analysed as follows :

Constituent	Assay %
Cu	0.99
Fe	23.10
S	6.08
SiO ₂	42.38
Al ₂ O ₃	11.40
MgO	5.96
Au	0.14 dwt/tonne
Ag	2.26 dwt/tonne

Mineralogical examination indicated that chalcopyrite was associated with other metallics like magnetite, pyrrhotite, pyrite etc. and was found in the matrix of siliceous gangue. Chalcopyrite was liberated fairly at 150 mesh size.

Rougher copper concentrate produced under the optimum conditions of 72% -200 mesh grind, 0.05 kg/tonne of xanthate and 0.04 kg/tonne of pine oil at natural pH analysed 4.15% Cu with 94.7% Cu recovery in it. After three cleanings at pH 9.5, the final concentrate analysed 20.46% Cu with 82.0% Cu recovery in it. When the rougher concentrate was ground to pass 200 mesh and then cleaned, the concentrate analysed 29.72% Cu with 80.2% Cu recovery in it.

When the test was restricted to two cleanings, the concentrate analysed 24.6% Cu with 84.3% Cu distribution in it.

**(vi) Complex sulphides from Dariba—
Rajpura area**

In addition to the copper ores at Khetri, complex copper-lead-zinc ore occurred at Dariba-Rajpura area, in Rajasthan. Core samples and bulk samples have been tested from this deposit.

Core samples : Core samples ranging in size from 75 mm to 50 mm was received from the GSI for beneficiation tests.

The sample analysed as follows :

Constituent	Assay %
Cu	0.99
Pb	3.70
Zn	4.80
Fe	4.20
S	6.20
SiO ₂	47.50
CaO	1.30
Ag	90.0 gms/tonne

Microscopic examination of the samples indicated the presence of chalcopyrite, sphalerite, galena, pyrite and pyrrhotite which are well liberated from the non-metallic gangue constituting calcite, dolomite, amphiboles etc. at about 100 mesh size.

Rougher flotation tests conducted with optimum conditions of 67% -200 mesh grind, to depress zinc with 1.3 kg/tonne of lime, 0.6 kg/tonne of

zinc sulphate and 0.05 kg/tonne of NaCN and collecting a combined copper-lead float with 0.08 kg/tonne of pot. eth. xanthate and 0.075 kg/tonne of cresylic acid, the concentrate analysed 7.61% Cu, 28.70% Pb and 3.74% Zn with 95.4% Cu, 99.3% Pb and 9.7% Zn distribution.

Further treatment of the rougher Cu-Pb tails with 0.75 kg/tonne of lime, 0.6 kg/tonne of copper sulphate followed by 0.06 kg/tonne of xanthate and 0.05 kg/tonne of cresylic acid produced a rougher zinc concentrate assaying 37.5% Zn with 85.4% Zn distribution.

After two cleanings of the rougher Cu-Pb concentrate with 0.9 kg/tonne of lime, and 0.02 kg/tonne of xanthate followed by copper depression and lead floating with 0.25 kg/tonne of lime and 2.0 kg/tonne of sod. cyanide yielded a lead float analysing 63.49% Pb, 3.4% Cu and 4.06% Zn with 92.2% Pb distribution in it and a tailing (Cu conc.) analysing 24.6% Cu, 4.02% Pb and 2.54% Zn with 70.5% Cu distribution in it.

The rougher zinc concentrate after two cleanings with 1.0 kg/tonne of lime and 0.2 kg/tonne of sod. cyanide yielded a zinc concentrate analysing 53.82% Zn, 0.52% Cu and 0.30% Pb with 82.5% Zn distribution in it.

Attempts to collect pyrite and pyrrhotite from the rougher zinc tails with 2.5 kg/tonne of H₂SO₄, 0.1 kg/tonne of xanthate and 0.06 kg/tonne of pine oil, followed by one cleaning with 0.03 kg/tonne of xanthate yielded a pyrite pyrrhotite concentrate assaying 37.95% S, 0.65% Cu, 1.72% Pb and 3.1% Zn with 19.5% S distribution in it.

(vii) Bulk Sample

The sample was composed of 100 mm to 50 mm lump with little fines and analysed as follows :

Constituent	Assay%
Cu	0.42
Pb	1.72
Zn	6.20
Fe	3.03
S	6.29
BaO	10.02
SiO ₂	33.60
CaO	13.56
CaF ₂	3.18
MgO	3.00
Al ₂ O ₃	0.40
Ni, P, & Au	Trace

Mineralogical examination of the sample revealed the presence of the sulphides sphalerite, galena, chalcopyrite, and minor amounts of arsenopyrite, bornite, cubanite, violerite, enargite, pyrrhotite and covellite. The non-metallic gangue was composed of quartz, barite, dolomite, calcite, cerussite etc. The metallics were liberated fairly at 150 mesh size.

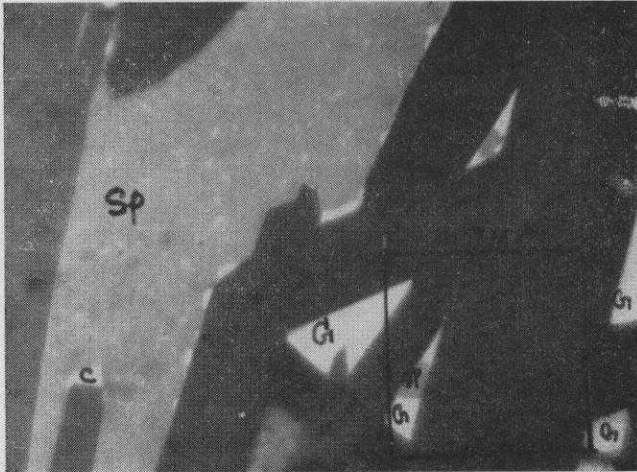


Fig. 3.9 Showing very fine inclusions of chalcopyrite (C) in Sphalerite (Sp) with partially replaced galena (G) and sphalerite (Sp) grains in a siliceous gangue matrix (Dark grey). Reflected illumination X600. The square represents 200 mesh (74 microns) opening. (Dariba—Rajasthan Copper-Lead-Zinc Ore).

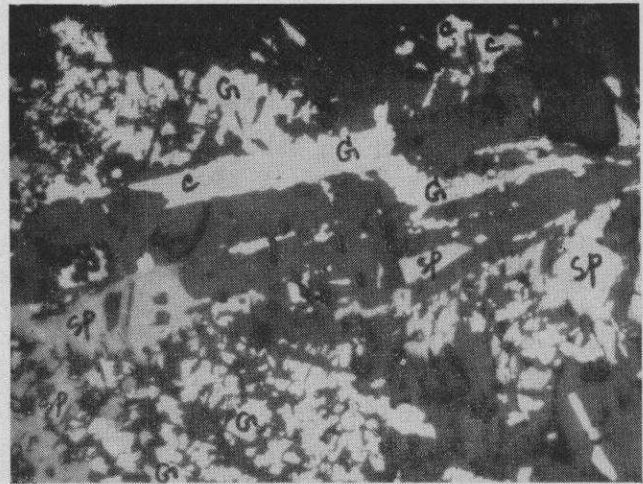
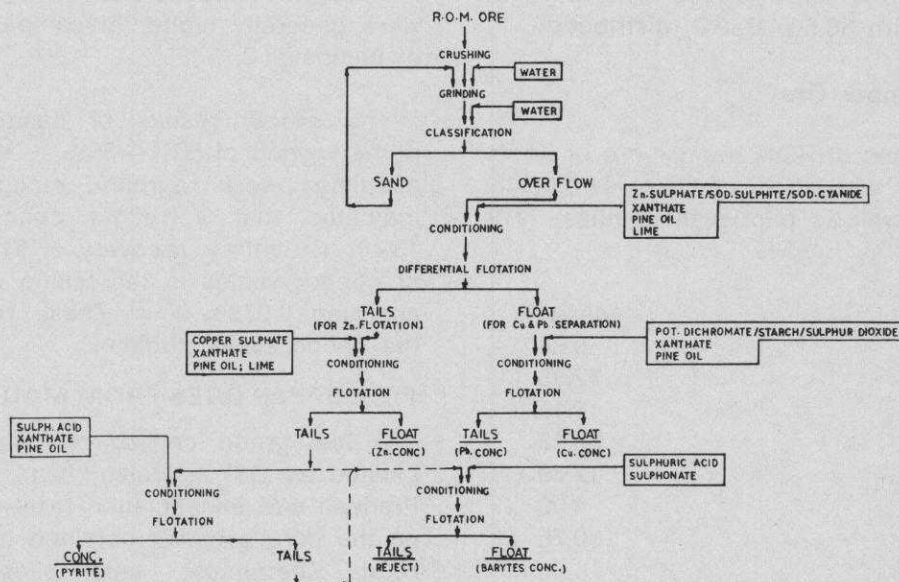


Fig. 3.10 Showing general finegrained nature of chalcopyrite (C), Sphalerite (Sp), galena (G) and Pyrite (P) in a siliceous gangue matrix (dark grey). Reflected illumination X150. Square represents 200 mesh (74 microns) opening. (Dariba Copper-Lead-Zinc Ore-Rajasthan).

Rougher flotation tests under the optimum conditions of 47% -200 mesh grind with 0.75 kg/tonne of lime, 1.0 kg/tonne of sod. silicate, 0.04 kg/tonne of sod. cyanide, 0.54 kg/tonne of zinc sulphate, 0.02 kg/tonne of pot. eth. xanthate and 0.44 kg/tonne of cresylic acid for bulk Cu-Pb concentrate analysing 2.31% Cu, 11.23% Pb, and 4.76% Zn with 89.9% Cu, 100.0% Pb and 21.1% Zn distribution; and 2.5 kg/tonne of lime, 1.4 kg/tonne of copper sulphate, 0.26 kg/tonne of xanthate and 0.44 kg/tonne of cresylic acid for



Flowsheet 3:5—Flowsheet for beneficiation of copper-lead zinc sulphide ores

zinc concentrate that analysed 0.22% Cu, trace of Pb and 34.2% Zn with 8.4% Cu and 85.1% Zn distribution in it.

Four cleanings of the bulk Cu-Pb concentrate with 2.7 kg/tonne of lime, 0.5 kg/tonne of sod. silicate, 0.115 kg/tonne of xanthate and 0.022 kg/tonne of cresylic acid rejecting the tailings followed by separation of lead in float and copper in tails with 0.30 kg/tonne of lime and 2.4 kg/tonne of sod. cyanide produced a copper concentrate analysing 19.1% Cu, 4.0% Pb, 3.55% Zn and 364 gm/tonne of Ag with 66.4% Cu recovery, and a Pb concentrate analysing 60.5% Pb, 2.95% Cu, 3.07% Zn and 504 gms/tonne Ag with 87.1% Pb recovery in it.

Rougher zinc concentrate after four cleanings with 2.0 kg/tonne of lime, 0.25 kg/tonne of sod. silicate 0.58 kg/tonne of xanthate and 0.44 kg/tonne of cresylic acid yielded a concentrate analysing 52.9% Zn, 0.19% Cu and trace of lead with 73.5% Zn distribution. The distribution of zinc may be improved when the cleaner tails are recirculated.

Tabling tests with the deslimed primary tails after recovering the Cu, Pb & Zn sulphides, produced a barytes concentrate analysing 62.5% BaSO₄ with 73.6% BaSO₄ distribution in it. Further three cleaning of the table concentrate with 3.5 kg/tonne of lime and 0.55 kg/tonne of Aero-promotor 825 produced a final barytes concentrate assaying 90.1% BaSO₄, 0.07% Zn and traces of Cu and Pb with 56.6% BaSO₄ distribution.

(viii) Khetri Copper Ore

About 100 tonnes of ROM copper ore of Khetri copper complex was received from H.C.L. for bench scale as well as pilot plant studies. The sample analysed as follows:

Constituent	Assay%
Cu	0.88
Fe	12.88
S	2.15
SiO ₂	58.18
Al ₂ O ₃	12.89
MgO	4.00
CaO	0.75

Mineralogical examination of the sample indicated the presence of chalcopyrite as the chief

copper mineral while pyrite, pyrrhotite and magnetite formed the metallic gangue minerals. Minor quantities of pentlandite, ilmenite and rutile were also observed.

Several bench scale flotation tests indicated that under the optimum conditions of 50 to 55% —200 mesh grind with 0.05 kg/tonne of sodium isopropyl xanthate and 0.186 kg/tonne of pine oil with a total of 6 mts. conditioning time and 4 mts. of flotation time a concentrate assaying about 14.0% Cu with 92.0% copper distribution in it had resulted. Finer grinding did not appreciably improve the recovery. Locked tests indicated the desirability of regrinding middlings in the mill used for grinding fresh feed. The concentrates from locked tests required one cleaning to yield a final concentrate of acceptable grade of 12% to 16% Cu. The primary tailings were having consistent values assaying less than 0.07% Cu with not more than 6% —8% Cu distribution.

Based on the results of bench scale flotation studies, continuous pilot plant studies were undertaken with a view to confirming the laboratory test results and to study middling recirculation etc. These tests were conducted using grinds of about 50%—55% —200 mesh for rougher flotation. Two campaigns were run. In campaign-1 the middlings were returned to the circuit without regrinding, whereas in campaign-2 the middlings were reground along with the fresh mill feed. The results showed that tailing analyses were generally higher in campaign-1 than those of campaign-2.

The overall results of campaign-2 with the primary grind of 50%—55% —200 mesh and the middlings were reground along with the feed indicated that a refloat concentrate assayed 13.4% Cu with a recovery of 91.7% in it. Loss of copper values in the tailing was 8.3% which analysed 0.075% Cu. These results confirmed the bench scale studies.

F. COPPER ORES FROM MADHYA PRADESH

A low grade copper ore deposit had been located by GSI in Malanjkhanda area, in Madhya Pradesh and beneficiation tests were carried out on the core samples obtained from GSI through H.C.L. Khetrinagar. Later pilot plant scale investigation was also taken up on a large tonnage of sample received from H.C.L.

(i) Core sample from Malanjkhanda

The core sample drawn from Malanjkhanda copper ore deposit was received for beneficiation studies. The sample analysed as follows:

Constituent	Assay%
Cu	0.645
Fe	2.73
S	0.86
SiO ₂	72.24
Al ₂ O ₃	6.49
MgO	1.40
CaO	2.37
Mo, Pb & Zn	Trace

Mineralogical examination indicated that chalcopyrite was the chief ore mineral. Pyrite, goethite, magnetite and traces of sphalerite were also observed. Quartz and feldspars formed the non-metallic gangue. Chalcopyrite was liberated at 35 to 48 mesh size.

Tabling tests conducted with a sized feed of 20 mesh size produced a combined concentrate analysing 2.3% Cu with 58.1% Cu distribution in it. Slimes carried 18.5% of total copper present in the sample.

Flotation tests conducted under optimum conditions of 62.6% -200 mesh grind, 0.03 kg/tonne of xanthate and 0.016 kg/tonne of pine oil at natural pH produced concentrate analysing 15.0% Cu with 91.4% Cu distribution. Use of higher xanthates and sod. sulphide had indicated 3% increase in the recoveries. Tests employing 1:1 pot. eth. xanthate and pot. amyl. xanthate mixture after sulphidisation with 0.1 kg sod. sulphide produced a concentrate analysing 13.3% Cu with 95.19% Cu distribution. The rougher concentrate after two cleanings produced a concentrate analysing 25.8% Cu with 92.17% Cu distribution in it.

(ii) Bulk Copper Ore from Malanjkhanda

Two different lots of copper ore from Malanjkhanda weighing 50 tonnes and 76 tonnes were received from HCL for bench and pilot plant scale investigation. The test sample was prepared at the instance of HCL by mixing 30% and 70% of the respective lots after crushing to 50 mm size. The composite test sample analysed as follows:

Constituent	Assay%
Cu	1.00
SiO ₂	81.60
Al ₂ O ₃	5.51
Fe	3.99
CaO	1.09
MgO	1.41
S	1.50
Ni	0.01
Mo	0.008 (Spectrophotometric)
UO ₃	Not detectable
Pb & P	Trace

Microscopic examination revealed the presence of chalcopyrite, covellite and chalcocite which contribute copper in association with the other metallic minerals like pyrite, magnetite and hematite. Minor amounts of tetrahedrite, arsenopyrite, enargite, bravoite, goethite, ilmenite, azurite and malachite were also observed. Quartz and feldspar associated with pyroxenes and mica formed non-metallic gangue. Chalcopyrite and pyrite were liberated at 65 mesh size.

Batch scale tests indicated that a grind of 56% -200 mesh, 0.14 kg/tonne of xanthate and 0.048 kg/tonne of MIBC at natural pH were optimum to produce a rougher copper concentrate analysing 9.2% Cu with 97.1% Cu distribution. Pine oil in place of MIBC gave slightly lower recoveries. When a 1:1 mixture of pt. amyl and isopropyl xanthates was used under similar conditions, the concentrate analysed 7.25% Cu with 98.3% Cu distribution. After two cleanings, the concentrate analysed 27.9% Cu with 96.8% distribution.

(iii) Malanjkhanda Cu Ore Pilot Plant Studies

Continuous pilot plant tests were conducted on 126 tonne bulk sample drawn from the Malanjkhanda deposit.

The ROM ore was crushed in a primary jaw crusher set to 50 mm gap followed by secondary crushing to 12 mm in cone crusher operating in closed circuit with a vibrating screen. The crushed 12 mm ore was sent to the ore bin from where it was fed through a constant weight feedometer to a 183 cm & 91.5 cm ball mill operating with a rake classifier. The classifier overflow was sent to a conditioner where the xanthate was added and MIBC was added at the outlet of the conditioner.

Rougher flotation of the copper ore was done in a battery of 12 Nos. of 2.75 Cu ft. vol. Denver Sub-A type of cells and the tailings were rejected after water reclamation for recirculation. The rougher concentrate was cleaned initially in a battery of 3 Nos. 1.5 Cu ft. vol. Sub-A cells and the second cleaned in a similar type of 2 cell battery. The cleaner tails were recirculated to the conditioner.

Pilot plant studies indicated that the optimum conditions for the treatment of Malanjhand copper ore were.

1) 56% -200 mesh grind 2) 0.045 kg/tonne of xanthate 3) 0.016 kg/tonne MIBC 4) 21% solids for rougher flotation and 5) 24 Mts. of flotation time where in 27.9% Cu grade concentrate with 96.8% Cu distribution was produced.

G. COMPLEX ORES FROM SIKKIM & NEPAL

Apart from the various copper ores mentioned so far, complex copper-lead-zinc ores obtained from Nepal and Sikkim were tested for the concentration of the three sulphides separately. Concentration of copper minerals has been dealt here whereas the concentration of the lead and zinc minerals has been furnished on the following chapter.

(i) Sikkim Ore

The sample was received from Bhotang mines in Sikkim thro' the Indian Bureau of Mines. The sample received was composed of lumps upto 75 mm down to fines and analysed as under :

Constituent	Assay%
Cu	0.67
Pb	1.48
Zn	4.50
S	8.68
Fe	15.22
SiO ₂	58.20
Al ₂ O ₃	6.70
MgO	1.87
Co, Cd & Ni	Trace
Ag	21.1 oz/ton.
Au	Trace

Microscopic examination revealed that chalcocite, sphalerite and galena were the respective

minerals for the contribution of copper, zinc and lead. The other metallics present in the sample were pyrite, pyrrhotite, arsenopyrite and marcasite. The non-metallic gangue was composed of quartz, chlorite, garnet and minor amounts of pyroxenes. Liberation of the important minerals was observed at 325 mesh size.

Differential flotation tests producing a copper-lead bulk concentrate followed by the flotation of zinc sulphide was adopted with feed ground to 80% -200 mesh size. The pulp was conditioned with 4.5 kg/tonne of soda ash, 0.3 kg/tonne of sod. sulphide, 0.75 kg/tonne of zinc sulphate and 0.025 kg/tonne of sod. cyanide to adjust the pH of the pulp and to depress the zinc sulphide. Then the bulk copper-lead concentrate was collected employing 0.015 kg/tonne of xanthate and 0.1 kg/tonne of cresylic acid. The pulp was later treated separately for the recovery of zinc minerals. The rougher concentrate thus obtained analysed 8.2% Cu and 15.2% Pb with 80.7% Cu and 75.5% Pb distributions in it. The rougher Cu-Pb concentrate was reground to -325 mesh was cleaned twice after passing sulphur dioxide in the pulp and again adding soda ash and xanthate rejecting the sphalerite and pyrrhotite in the cleaner tails. Then two lead floats were taken followed by a final copper concentrate. The copper concentrate thus obtained analysed 27.55% Cu with 64.1% Cu distribution.

Pre-concentration by HMS method with -25 mm +10 mm at 2.8 sp.gr. reduced the bulk of the feed to flotation by rejecting 43.7% of the HMS feed with 5.9% Cu, 2.8% Pb and 3.1% Zn distribution in it. The HMS concentrate i.e. Sink at sp.gr. of 2.8 when put to flotation along with the untreated -10 mm fines produced copper concentrates, similar to those obtained by direct flotation.

(ii) Nepal Ore

The sample was received from M/s. Nepal Minerals Supply Co., Kathmandu and was drawn from Mahabharat Area, Beraghari Dist., Nepal. The sample in its as received state, consisted of lumps from 10 mm to 30 mm and without fines. Complete chemical analysis of the sample was as follows :

Constituent	Assay%
Cu	1.13
Pb	4.10
Zn	1.00
Fe	33.90
S	23.80
SiO ₂	10.31
Al ₂ O ₃	0.83
LOI	11.62
Moisture	1.82
Bi	Minute Trace
Ag, Ni, As & Sb	Not detected

Mineralogical examination of the sample indicated that chalcopyrite, galena and sphalerite formed chief ore minerals, and the other metallics were, pyrrhotite which was in great abundance followed by pyrite, and magnetite. Trace amounts of arsenopyrite, bismuthinite, jamesonite and hematite were also observed. The non-metallic gangue was composed of tremolite, actinolite, epidote, garnet, calcite and quartz. Sulphides were liberated at 100 mesh size. Copper and lead minerals were free from the rest of the sulphides at 200 mesh size; sphalerite was disseminated in all the sulphides and the liberation was at a very fine size and the liberation and concentration might be difficult.

The bulk sulphide concentrate produced under the optimum conditions of 93% -200 mesh grind,

0.03 kg/tonne of xanthate and 0.06 kg/tonne of cresylic acid analysed 1.75% Cu, 6.36% Pb and 1.15% Zn with respective recoveries of 95% Cu, 94.9% Pb and 63.5% Zn in it. Use of higher xanthates did not show any improvement.

Bulk Cu-Pb concentrate produced by differential flotation depressing sphalerite analysed 5.77% Cu and 18.41% Pb with respective recoveries of 80.1% Cu & 70.4% Pb in it. Similar test after magnetic separation produced a bulk Cu-Pb concentrate analysing 6.55% Cu and 22.0% Pb with 81.1% Cu & 73.3% Pb recoveries in it. In all the products pyrrhotite was present which could not be separated completely by magnetic separation alone.

Bulk sulphide concentrate when cleaned four times with 0.08 kg/tonne of sod. cyanide at pH 8.5 to 9.0 and 0.04 kg/tonne of cresylic acid, and when the final product was subjected to high intensity magnetic separation followed by selective flotation with 2.0 kg/tonne of sod. cyanide, produced a tailing containing all the chalcopyrite analysing 22.82% Cu with 76.7% distribution. The float which contained bulk of galena analysed 65.21% Pb with 80.1% distribution. The magnetic and cleaner flotation tails constituted the rest of sulphides incidentally producing a pyrite-pyrrhotite conc. analysing 35.38% S with 80.3% S distribution in it.

TABLE 3.4—BENEFICIATION RESULTS OF NICKEL AND COPPER-LEAD-ZINC ORES

State & Locality	Feed Assay %	Beneficiation Method	Conc. Assay %	Conc. Recovery %	Remarks
Orissa					
(1) Sukinda Nickel Ore	1.00 Ni	—	—	—	Not practicable by Ore Dressing.
Assam					
(2) Nickel Ore	0.48 Ni	—	—	—	"
Bihar					
(3) Mosabani No. 1	2.2% Cu 0.0804% Ni	Xanthate flotation for 30 mts.	12.5% Cu 0.31% Ni	96.5% Cu 65.6% Ni	
(4) Mosabani No. 2	1.80% Cu 0.08% Ni	Rougher flotation followed by one cleaning	22.6% Cu 0.41% Ni	95.2% Cu 38.9% Ni 83.9%	Pilot plant scale investigation. Elevated temp. produced 54.8% Ni recovery.
(5) Rakha mines No. 1	2.73% Cu 0.072% Ni	Xanthate flotation	24.25% Cu	97.6% Cu	
(6) Rakha mines No. 2	1.34% Cu 0.053% Ni	Rougher xanthate flotation for 30 mts. followed by one cleaning	22.07% Cu 0.28% Ni	87.4% Cu 25.3% Ni	Pilot plant scale tests including Mo recovery.
(7) Rakha mines No. 3	0.92% Cu .0205% Ni	Rougher flotation with 2 cleanings	25.5% Cu 0.28% Ni	87.38% Cu 31.00% Ni	Pilot plant scale test. mixed xanthates were used.
Jaduguda : Uranium					
(8) Ore—No. 1	0.17% Cu 0.17% Ni	Bulk sulphide concentration only for molybdenite.	0.94% Cu 1.84% Ni	32.6% Cu 63.8% Ni	Pilot plant scale tests. Low Cu recoveries.
(9) Ore—No. 2	0.24% Cu	Bulk sulphide concentration only for molybdenite	1.16% Cu 1.72% Ni	55.1% Cu 70.0% Ni	Low Cu recoveries.
(10) Ore—No. 3	0.18% Cu 0.20% Ni	Flotation for 24 min. with xanthate	1.92% Cu 3.35% Ni	41.8% Cu 65.8% Ni	Selective flotation for moly. followed by Cu-Ni flotation.
(11) Ore—No. 4	0.14% Cu 0.17% Ni	Xanthate rougher flotation followed by cleanings	1.16% Cu 1.57% Ni	28.3% Cu 31.6% Ni	Selective flotation of moly. followed by Cu-Ni flotation pilot plant scale test.
(12) Copper ore from Chapri, Singh-bhum Dist., HCL	0.48% Cu Chalcopyrite, magnetite, pyrite; gangue=Biotite, Chlorite, Quartz	Flotation	22.6% Cu	88.6% Cu	
Andhra Pradesh					
(13) Nallakonda block Agnigundala area	9.92% Cu	Rougher flotation and one cleanings	26.6% Cu	88.9% Cu	Rougher conc. analysed 21.3% Cu with 94% dist.
(14) Dhukonda block	1.24% Cu 0.6 gm/t. Ag	Rougher xanthate, flotation and one cleaning	24.42% Cu	92.0% Cu	Rougher conc. analysed 17.88% Cu with 93.7% Dist. contained 9 gm/ton Ag of silver.

TABLE 3.4—Continued

Rajasthan				
(15) Bhagani area	1.16% Cu Rougher xanthate flotation and one cleaning	21.6% Cu	92.0% Cu	Calcite/dolomite conc. assaying 30.52% CaO with 47.1% dist. from the Cu tails with fatty acid flotation.
(16) Kolihan area	2.69% Cu 2.6 dwt/t Ag 0.19 dwt/t Au 0.80% Cu	Rougher xanthate flotation and one cleaning	93.8% Cu	From the rougher & cleaner Cu tails a sulphide conc. assaying 38.0% S with 40.4% S dist. reduced as by product. Pyrite-pyrrhotite conc. assaying 36.25% S and 29.0% S dist. may be produced from rougher tails.
(17) Khetri area	0.79 1.7 dwt/t Ag 0.08 dwt/t Au 0.99% Cu	Rougher xanthate flotation with two cleanings.	82.7% Cu	
(18) Khetri-Shaft No. 3	2.26 dwt/t Ag 0.08 dwt/t Au 0.99% Cu 3.70% Pb 4.80% Zn	Rougher xanthate flotation with three cleanings	75.5% Cu	
(19) Ghatwali Adit.	0.42% Cu 1.72% Pb 6.20% Zn 10.02% BaO 0.88% Cu	Rougher xanthate flotation with regrinding two cleanings.	84.3% Cu	
(20) Dariba-Rajpura-I		Rougher selective flotation of Cu & Pb followed by zinc flotation followed by cleaning and separation of the concentrates.	70.5% Cu 92.2% Pb 82.5% Zn	Core samples.
(21) Dariba-Rajpura-II		"	66.4% Cu 87.1% Pb 73.9% Zn	Bulk sample.
(22) Khetri copper ore from copper complex		Tabling followed by flotation. Flotation	90.1% BaSO ₄ Bench scale conc. 14.0% Cu Tails=0.07% Pilot plant scale Refloat conc. 13.4% Tails 0.075% Cu	By-product.
Madhya Pradesh				
(23) Malanjkhand core sample	0.645	Rougher xanthate flotation & 2 cleanings	92.17% Cu	Mixed xanthates gave better results.
(24) Malanjkhand	1.00	"	96.8% Cu	Mixed Pilot plant scale test.
Complex Cu-Pb-Zn Ores				
(25) Sikkim ore	0.67% Cu 1.48% Pb 4.50% Zn	Flotation of Zn sulphides followed by flotation of Cu-Pb sulphides. Two cleanings followed by differential flotation Cu sulphides—Pb tails	64.1% Cu	
(26) Nepal ore	1.13% Cu 4.10% Pb 1.00% Zn	Bulk sulphide flotation followed by 4 cleanings and separation to eliminate pyrrhotite and selective flotation of Pb minerals & Cu tails	76.7% Cu	Zn conc. was not possible cleaner tails and mag. conc. put together analysed 35.38% S with 80.3% S distribution

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