TUNGSTEN MINERALS

Wolframite and scheelite are the essential minerals of the strategic metal Tungsten and are known to occur in Rajasthan, Maharastra, West Bengal and Karnataka states. Mineral concentrate analysing over 60% WO_3 with minor amounts of impurities like Cu, Sn, Sb, Bi & As find use in the metallurgical industry.

Tungsten minerals are heavy and are usually beneficiated by gravity methods. In order to eliminate the other impurities, magnetic separation and flotation also may be employed.

A Wolframite from Agargaon, Nagpur dist., Maharastra:

A sample of low grade wolframite analysing 0.4% WO_3 was received from the Geological Survey of India for beneficiation tests. The sample was sandy in nature with a major bulk passing through 10 mesh screen.

Microscopic examination of the sample indicated the presence of hematite, goethite, magnetite and limonite minerals as metallic gangue while quartz, mica and tourmaline formed the non-metallic gangue minerals. Wolframite and scheelite were the wolfram bearing minerals. Wolfram minerals were liberated from the rest of the gangue at 65 mesh size.

The sample was treated on shaking table in its "as received" condition and after two cleanings the concentrate analysed 46.8% WO_3 with 60.8% distribution. After regrinding the second cleaner concentrate to 48 mesh size and another cleaning on the table, the concentrate analysed 60.1% WO_3 with 55.6% distribution. When all the table rejects were combined, ground to 48 mesh size and treated on tables a concentrate assaying 60% WO_3 with an additional recovery of 12% WO_3 was produced. Thus the final concentrate obtained from direct and regrinding treatments analysed 60.0% WO_3 with 67.6% distribution in it.

B Wolframite samples from Degana—Rajasthan:

Two samples were received from Degana area for beneficiation tests. Wolframite was the chief mineral followed by minor amounts of scheelite. The gangue was composed of quartz followed by small quantities of topaz, chlorite, hornblende, zircon, garnet, tourmaline etc.

Sample No. 1

The sample was composed of 10 mesh fines with occasional lumps of 50 mm in size. The lumps were crushed to pass 10 mesh screen. The sample in its as received state analysed 0.11% WO_3.

A representative portion of the 10 mesh sample was sized to +28, +65 and −65 portions. +28 portion when treated on jig produced a concentrate analysing 1.5% WO_3 with 80.4% distribution. When the jig concentrate was cleaned on a shaking table followed by magnetic separation, the magnetic concentrate analysed 48.79% WO_3 with 35.5% recovery. The +65 and—65 portions were treated on shaking table and the concentrate was subjected to magnetic separation. The magnetic concentrate obtained thus, analysed respectively 59.51% WO_3 with 10.8% distribution and 1.5% WO_3 with 1.9% distribution. The combined concentrate of jigging and tabling followed by magnetic separation analysed 25.29% WO_3 with 50.4% distribution in it. In another similar test, the jig concentrate instead of keeping separate was ground to 28 mesh size and treated on shaking table and magnetic separation, the coarse concentrate analysed 63.25% WO_3 with 37.9% distribution, the medium concentrate with 41.60% WO_3 and recovery of 9.5%, and the finer concentrate analysed 53.96% WO_3 with 10.3% recovery. When the concentrates were combined, the product analysed 56.6% WO_3 with 57.7% distribution.

Tabling and magnetic separation with ROM sample ground to 35 mesh size produced a concentrate assaying 66.3% WO_3 with 48.8% distribution.

If it is combined with the second concentrate analysed 53.3% WO_3 with 65.4% distribution. Tabling tests at 48 mesh size did not show any improvement but lowered the grade.

Humphry's spiral tests conducted with 20 mesh feed followed by sizing, tabling and magnetic separation produced a coarse concentrate assaying 65.82% WO_3 with 22.1% recovery and a finer concentrate assaying 51.41% WO_3 with 15.4% recovery. When the two concentrates were combined, the product analysed 59.02% WO_3 with 37.5% recovery.

Hence it may be concluded that if only 60% WO_3 and above grade of concentrate is to be produced,

after reducing the ore to 35 mesh size, the 65 mesh fines must be eliminated before treatment, wherein the recovery shall be only 48.8%.

Sample No. 2

The sample was composed of fines passing 10 mesh screen and analysed 0.052% WO_2. Straight tabling tests after reducing the feed size to 28 mesh size produced a concentrate assaying 1.21% WO_3 with 51.02% distribution. Jigging with —10+28 portion followed by size reduction to 28 mesh and treatment on tables along with —28 ROM portion followed by magnetic separation produced a concentrate analysing 5.45% WO_3 with 65.5% distribution. Tabling and magnetic separation at 48 mesh size yielded a concentrate assaying 13.63% WO_3 with 60.30% recovery. A complicated flowsheet known with a combined treatment of tabling, hydrocycloning, high tension separation, reduction roast and magnetic separation with 48 mesh feed, produced a concentrate assaying 36.00% WO_3 with 50% distribution.

C Scheelite from Karnataka:

Attempts have been made for the recovery of scheelite from the cyanidation tailings from the Kolar gold field. The sample was sandy in nature and analysed as follows:

Constituent	*Assay %*
WO_3	0.16
S	0.20
O	0.051
SiO_2	48.50
Fe	9.25
As	0.10
Mn	0.10
Sn, Bi, Sb, Cu, Zn, Pb & Ti	Trace

Tabling tests produced a concentrate assaying 21% WO_3 with 63% distribution. As the concentrate was associated with arsenopyrite, pyrite, magnetite etc., the product was roasted in a reduction atmosphere and subjected to magnetic separation. The non-magnetic portion obtained analysed 67.5% WO_3 with 59% distribution.

When the sample was treated in a hydrocyclone, followed by tabling, reduction roast and magnetic separation, the non-magnetic concentrate analysed 64.00% WO_3 with 63.12% distribution. Flotation studies in place of reduction roast and magnetic separation with the table concentrate did not produce any encouraging results.

Tabling, followed by reduction roast and magnetic separation tests with 48 mesh feed produced a concentrate assaying 67.8% WO_3 with 64.3% distribution. When the slimes were treated in a hydrocyclone, the underflow analysing 40% WO_3 with an additional recovery of 5% was recovered. When the non-magnetic concentrate and the cyclone underflow were combined, the concentrate analysed 60.8% WO_3 with 69% distribution in it.

D Wolframite from Chandapathar deposits, West Bengal:

Deposits of low grade wolframite are worked and manually beneficiated at Chandapathar area of Bankura Dist. in West Bengal.

The ore contained of wolframite and scheelite followed by minor amounts cuprite, tenorite, chalcopyrite, native copper, magnetite and ilmenite. Quartz formed the bulk of the non-metallic gangue followed by micas and tourmaline. The sample was composed of lumps from 160 mm to 25 mm with a small quantity of fines. Complete chemical analysis of the sample was as follows:

Constituent	*Assay %*
WO_3	0.143
Fe_2O_3	6.180
SiO_2	91.670
S	0.04
P	0.027
Cu	0.098
MgO	0.01
CaO & Al_2O_3	Trace

Sizing followed by tabling tests with 20 mesh feed produced a combined concentrate analysing 5.27% WO_3 with 38.1% distribution. Hydrosizing, tabling and magnetic separation with 28 mesh feed produced a concentrate assaying 6.93% WO_3 with 51.1% distribution. Tabling tests with 35 mesh feed followed by roasting and magnetic separation produced a concentrate analysing 59.74% WO_3 with

26.6% distribution. Tests with 25 mesh feed comprising sizing, tabling, with cleaning on tables, high tension separation and cleanings separately for the coarse and fine products produced a combined concentrate assaying 59.1% WO_3 with 49.07% distribution.

The optimum results of the various samples are tabulated and given in Table 5.1

References

1) Beneficiation of a low grade wolframite from Degana-Rajasthan (NML. IR. NO. 668/72). By R. K. Kunwar, D. M. Chakrabarti & G. P. Mathur.

2) Concentration of low grade wolframite from Degana-Rajasthan (NML. IR. NO. 11/52). By S. K. Banerjee & P. I. A. Narayanan.

3) Beneficiation of a low grade wolframite sample from Agargaon-Nagpur Dist.—Maharastra (NML. IR. NO. 805/74) By C. Satyanarayana, P. V. Raman, S. K. Banerjee & G. P. Mathur.

4) Beneficiation of a low grade run-of-mine wolframite sample from Chandapathar mines Bankura Dist. West Bengal. (NML. IR. NO. 759/73). By S. K. Sengupta, S. Raghunadha Rao, S. K. Banerjee & G. P. Mathur.

5) Recovery of scheelite from Walker's dump K. G. F. Karnataka (NML. IR. NO. 667/72). By R. K. Kunwar, P. V. Raman & G. P. Mathur.

GRAPHITE

Graphite is a very essential and important mineral generally used for the manufacture of crucibles, furnace electrodes, pencils, batteries, foundry facing etc. Flaky type of graphite is mostly used for the crucible manufacture.

Graphite occurs as veins in the host rock and the usual associated gangue minerals are quartz, micas and other silicates. Graphite being a lighter mineral, when liberated at coarser size is concentrated or pre-con centrated on shaking tables and then processed by flotation method. Graphite is a naturally floatable mineral and, as such, requires no collector. Pine oil or MIBC are used as frothers. Occasionally a minute quantity of kerosene oil and sodium silicate may be used for the better separation of graphite and the gangue.

Various samples of low grade graphite ore from Andhra Pradesh, Rajasthan, Madhya Pradesh, Assam, Bihar, Kerala and Karnataka States have been tested in NML for their beneficiation.

A Graphites from Andhra Pradesh:

Graphite occurs in the metamorphosed Khondolite rocks of Eastern Ghats which extend almost all along

TABLE 5.1—TUNGSTEN ORE BENEFICIATION RESULTS

State & Locality	ROM ore Assay % WO_3	Beneficiation Method	Conc.		Remarks
			Assay % WO_3	% Recy.	
Maharastra:					
(1) Agargaon	0.4	Tabling followed by regrinding & cleaning	60.0	67.6	
Rajasthan					
(2) Degana (1)	0.11	Tabling & Magnetic separation	66.3	48.8	
(3) Degana (2)	0.052	Tabling, sizing, High tension separation, reduction roast & Mag. Separation	36.00	50.0	
Karnataka:					
(4) Kolar Tails	0.16	Tabling, reduction roast, Mag. Separation & Cyclone treatment	64.00	63.12	The WO_3 mineral is scheelite
West Bengal:					
(5) Chandapathar	0.143	Tabling, sizing & cleaning	59.1	49.07	

the coastal line. Graphite also occurs in the interior parts of Andhra Pradesh in the Daccan trap areas.

(1) Graphite from Khammam District

A low grade graphite sample was received from M/s. Indian Plumbago Co. Bombay drawn from K. G. Mines Khammam Dist.

The sample ranged in size from 100 mm down to fines. Complete chemical analysis of the sample was as follows:

Constituent	*Assay %*
Fixed Carbon	19.7
Ash	71.7
Moisture + Volatile matter	8.6
Fe in ash	5.3
S	1.7

Microscopic examination indicated the presence of both flaky and amorphous varieties of graphite. Minute inclusions of silicate minerals were observed in the graphite. Quartz and felspars followed by minor amounts of pyrite and goethite formed the gangue.

Flotation tests indicated that under the optimum conditions of 73% —200 mesh ground feed, 0.5% kg/tonne of sod, silicate and 0.12 kg/tonne of pine oil, a rougher graphite concentrate with 34.8% ash was produced. After regrinding the rougher concentrate 75% —200 mesh and two cleanings with 2.0 kg/tonne of sod. silicate and 0.03 kg/tonne of pine oil, a graphite concentrate containing 17.5% ash with 2.3% ash distribution in it was produced.

(2) Graphite from Gangavaram

The graphite sample was received from M/s. S. Lal & Co. Calcutta, drawn from Gangavaram area in Mehabubabad Dist., Andhra Pradesh. Complete chemical analysis of the sample was as follows:

Constituent	*Assay %*
Fixed Carbon	19.83
Ash	74.17
S	1.03
Fe in ash	6.06
Volatile matter	7.93
Moisture	0.77

Mineralogical examination of the sample indicated the presence of flaky and amorphous varieties of graphite. The gangue was composed of felspars, serpentines, quartz and mica followed by minor amounts of magnetite, pyrite and covellite. Graphite was interlocked with gangue even at 150 mesh size.

Flotation tests conducted under the optimum conditions of 62.1% —200 mesh feed grind, 0.5 kg/tonne of sod. silicate and 0.15 kg/tonne of pine oil produced a rougher graphite concentrate assaying 46.86% ash with 27.6% ash distribution. When the rougher concentrate was ground to 82% —200 mesh size and cleaned four times, it yielded a concentrate containing 32.18% ash. Rougher flotation with a calcined feed (950°C) under optimum conditions followed by 98% —200 mesh regrinding and four cleanings produced a concentrate assaying 79.47% Fc, 18.24% ash and 2.122% volatile matter.

(3) Graphite from Erramettala

A graphite sample drawn from Erramettala mine was received from M/s. S. Lal & Co., Calcutta, for beneficiation studies. The sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	21.80
Ash	67.10
S	0.20
Fe in ash	9.60
Volatile matter	9.60
Moisture	1.40

Examination of the sample under microscope indicated the presence of crystalline, flaky and amorphous varieties of graphite in the gangue matrix composed of siliceous minerals. Minor amounts of magnetite and goethite were also present. Graphite was not completely liberated even at 200 mesh size.

Flotation tests under optimum conditions of 84.4% —200 mesh grind with 0.5 kg/tonne of sod. silicate produced a rougher concentrate analysing 45.06% ash. After 3 cleanings with 0.25 kg/tonne of sod. silicate for each cleaning; the concentrate analysed 38.95% ash in it. When the rougher concentrate was ground to 100% —200 mesh size followed by three cleanings, the product analysed 28.5% ash in it. Roughing, regrinding and cleaning tests conducted with a calcined

feed produced a concentrate analysing 74.23% F. C., 24.19% ash and 1.45% volatile matter in it.

(4) Graphite from Sitapalli mines

A low grade graphite sample drawn from Sitapalli mines was received from M/s. S. Lal & Co., Calcutta, for the production of a graphite concentrate assaying 80% F. C. The sample had the following analysis:

Constituent	*Assay %*
Fixed Carbon	17.00
Ash	79.93
Volatile matter	2.51
Moisture	0.56
S	0.19
Fe in ash	20.42

The ore consisted of garnet and quartz as the chief gangue minerals followed by felspar and hematite. Graphite was liberated at 150 mesh size.

Flotation concentrate produced under optimum conditions of 55% —200 mesh grind, 0.04 kg/tonne of kerosene oil and 0.02 kg/tonne of pine oil analysed 30.7% ash. After two cleanings employing 0.24 kg/tonne of sod. silicated, the concentrate analysed 82% FC with 91.5% FC recovery, 15.6% ash and 2.16% V.M. After further two cleanings, the product analysed 85.24% F.C. with 76.4% F.C. recovery and 12.6% ash in it. Regrinding the rougher concentrate to 60% —200 mesh followed by four cleanings, the product analysed 87.35% F.C. with 67.18% F.C. recovery and 10.49% ash in it.

(5) Graphite from Khammam

The sample consisting 130—0 mm lumps was received from the Andhra Pradesh Industrial Development Corporation for beneficiation to produce a crucible grade concentrate. The sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	22.8
Ash	67.8
Fe in ash	8.7
Volatile matter	7.3
S	2.1
Moisture	2.1
MgO	0.3
CaO	0.5

Quartz, felspar and micas formed the bulk of the gangue with traces of carbonates and garnets. Graphite was fairly liberated at 65 mesh size but good grade may be obtained at 250 mesh size only. Flotation tests indicated that under the optimum conditions of 200 mesh feed employing 0.75 kg/tonne of sod. silicate and 0.06 kg/tonne of pine oil with three cleanings, a concentrate assaying 69.2% F.C. and 25.1% ash may be obtained. 50% fixed carbon was distributed in the concentrates. Further cleaning did not improve the grade to any great extent. This concentrate may be used for foundry facings.

B Graphite from Assam:

A low grade graphite sample received from Lohit Dist, NEFA area was received from Supt. Geologist, G.S.I., Assam Circle. The sample analysed as followed:

Constituent	*Assay %*
Fixed Carbon	2.15
Ash	95.75
Volatile matter	1.54
Moisture	0.56
S	0.30
Fe in ash	5.70
Cu & CO	Trace

Microscopic examination of the sample indicated that small amounts of crystalline and amorphous graphite were present in the gangue composed of micas and quartz with minor amounts of goethite and pyrite. Grain size of graphite being very minute, it may not be possible to produce good grade of concentrate from the ore.

Rougher graphite concentrate produced under the optimum conditions of flotation 84.2% —200 mesh grind with 0.5 kg/tonne of sod. silicate and 0.8 kg/tonne of pine oil — analysed 82.6% ash with 12.8% ash distribution in it. After four cleanings employing 1.0 kg/tonne of sod. silicate, the concentrate analysed 31.2% FC and 60.48% ash. Similar cleaning test with a reground feed analysed 45.13% FC and 51.0% ash with 46.2% FC and 1.1% ash distribution in it.

C Orissa Graphite:

A sample of high grade graphite was received from M/s. National Carbon Co., Calcutta, for upgrading

the same to better grade concentrate. The sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	77.85
Ash	17.60
Volatile matter	4.15
Moisture	0.40
S	0.51
Fe in ash	6.50
Cu	Trace
As, Sb & Ni	Nil

Microscopic examination revealed that graphite was of flaky and crystalline in nature and was associated with quartz and minor amounts of pyrite and hematite. Graphite and silicates were liberated at 100 mesh size but the silicate inclusions in graphite could be separated at a size of 12 microns only.

Flotation tests indicated that under the optimum conditions of 60.5% —200 mesh grind, 0.5 kg/tonne of sod. silicate and 0.15 kg/tonne of pine oil, a rougher concentrate analysising 11.69% ash may be produced. A mixture of light diesel oil and pine oil was used later as the mixture gave better results against pine oil alone. When the rougher concentrate was cleaned thrice employing 0.75 kg/tonne of sod. silicate and 0.075 kg/tonne of pine oil, the concentrate analysed 89% FC with 97.3% FC recovery and 7.1% ash. Similar cleaning tests with a 80% —200 mesh reground feed yielded a final concentrate analysing 90% FC with 99% FC recovery and 6.4% ash.

D Bihar Graphite:

A low grade graphite sample was received from M/s. Singhania Commercial Co., Calcutta, for the production of battery grade concentrate. The sample analysed as follows :

Constituent	*Assay %*
Fixed Carbon	15.50
Ash	76.20
S	6.50
Fe in ash	12.94
Cu	0.15
V.M.+Moisture	1.80

Mineralogical examination revealed the intimate association of soft and friable variety of graphite with the gangue composed of quartz, felspar and pyrite. Minor amounts of goethite, laterite and chalcopyrite were also observed. Graphite liberation was not complete even below 200 mesh size.

Flotation tests under the optimum conditions of 79.4% —200 mesh grind, 0.5 kg/tonne of sod. silicate, 0.65 kg/tonne of lime (pH 9.5) and 0.15 kg/tonne of pine oil yielded a rougher concentrate assaying 39.0% ash. After three cleanings, the concentrate analysed 14.34% ash. Regrinding the rougher concentrate to 88% —200 mesh followed by four cleanings the final concentrate analysed 88.0% FC with 90.8% FC recovery, 6.5% ash and 4.7% volatile matter and moisture.

E Graphites from Rajasthan

Three different samples were received in NML from the State Mineral Development Corporation and State Mining and Geology Department of Rajasthan.

(1) Graphite from Lotiyana area—Ajmer Dist.

The sample was received from the Director of Mining & Geology Dept. and analysed as follows :—

Constituent	*Assay %*
Fixed Carbon	2.17
Ash	84.03
Volatile matter	13.52
Moisture	0.28

Graphite was in very intimate association with mica even at —200 mesh size and all the attempts to produce even a low grade concentrate were not successful.

(2) Graphite from Doomara

The sample was received from the Director of State Mining & Geology Dept. and had the following analysis :—

Constituent	*Assay %*
Fixed Carbon	8.19
Ash	84.37
Volatile matter	4.92
Moisture	2.52

The chief gangue minerals were micas and quartz with smaller amounts of tourmaline and calcite. They are not free even at 200 mesh size. On flotation rougher concentrate produced under the optimum conditions of 96% —200 mesh grind, 2.0 kg/tonne of sod. silicate, 0.27 kg/tonnes of pine oil and 0.20 kg/tonne of light diesel oil analysed 67.94% ash, with 28.3% ash distribution in it. When the rougher concentrate was cleaned with 0.5 kg/tonne of lactic acid to depress mica, the concentrate analysed 56.65% ash will 3.5% ash distribution in it.

(3) Graphite received from State Industrial and Mineral Development Corporation

The graphite sample was to be upgraded for use in the battery, carbon brush or crucible industry. The complete chemical analysis of the sample in its "as received" state was as follows :

Constituent	*Assay %*
Fixed Carbon	5.83
Ash	81.17
Volatile matter	11.79
Moisture	1.21
S	1.71
Fe in ash	4.93
Cu in ash	0.25

Mineralogical examination of the sample revealed that the graphite was flaky in nature and was associated with the gangue composed of quartz, calcite, dolomite with smaller amounts of iron oxides and pyrite. Graphite was liberated at 150 mesh size.

Rougher flotation concentrate produced under the optimum conditions of 72% —200 mesh grind, 0.6 kg/tonne of Katha, 0.5 kg/tonne of sod. silicate and 0.12 kg/tonne of pine oil, analysed 20.7% FC and 65.2% ash with 93.6% FC recovery in it. After six cleanings using 0.3 kg/tonne of sod. silicate and 0.2 kg/tonne of Katha, the concentrate analysed 50% FC and 30.5% ash with 62.0% FC recovery in it. Rougher concentrate after regrinding to 95.3% —200 mesh grind and six cleanings as earlier produced a concentrate analysing 86.26% FC, 4.86% Volatile matter, 8.37% ash with 76.1% FC distribution it it. This product is suitable for use in battery, carbon brush, crucible industries.

(4) Graphite from Banswara

Graphite samples from Tantia, Sasakota and Kesharpura mines of Banswara district were received from Rajasthan State Industrial and Mining Development Corporation for beneficiation studies.

Batch tests were conducted separately on the three samples and pilot plant tests were conducted on a composite samples prepared by mixing Tantia and Sasakota samples in equal quantities.

Tantia Sample

The sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	16.32
Ash	68.46
Volatile matter	13.53
S	0.41
Fe in ash	2.48
CaO	12.68
MgO	0.73
CO_2	10.12
Moisture	1.28

Mineralogical studies on the sample revealed the presence of quartz, felspar, pyroxene and kaolinite as the chief gangue minerals followed by minor amounts of garnet, carbonates, sphene, biotite and hydrated iron oxides; graphite was liberated from the gangue at 35 mesh size.

Flotation tests with a grind passing 35 mesh screen with 0.5 kg/tonne sod. silicate and 0.015 kg/tonne pine oil produced a concentrate assaying 32.0% FC with 98.2% FC distribution in it. After two cleanings, the grade of the concentrate improved to 60.8% FC and 30.4% ash with 44.3% FC distribution in it.

Rougher flotation followed by regrinding and four cleanings yielded a grade of 86.1% FC and 9.6% ash with 77% FC distribution in it. Rougher flotation with 100 mesh feed followed by four cleanings yielded a concentrate assaying 88% FC and 7.6% ash with 72.4% FC distribution in it.

Sasakota Graphite

The sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	13.09
Ash	75.46
Volatile matter	11.48
CaO	17.14
MgO	5.21
CO_2	19.21
Fe in ash	4.03

Mineralogical examination revealed the presence of amphiboles and pyroxenes as the bulk gangue minerals followed by carbonates, quartz, and minor amounts of apatite, wollastonite, iron oxides and hydroxides. Graphite was liberated at 150 mesh size.

Rougher flotation at 28 mesh size followed by regrinding to 100 mesh and four cleanings produced a grade of 84.1% FC and 13.1% ash with 64.5% FC distribution in it.

Rougher flotation at 100 mesh size followed by four cleanings yielded a grade of 81.5% FC and 13.2% ash with 60.1% FC distribution in it.

Kesharpura Graphite

Complete chemical analysis of the sample was as follows:

Constituent	*Assay %*
Fixed Carbon	6.36
Ash	77.00
Volatile matter	15.36
CaO	20.00
MgO	5.80
CO_2	13.80
Fe in ash	3.92

Microscopic examination of the sample revealed the presence of the gangue minerals like amphiboles followed by quartz, carbonates and traces of biotite and garnet;. Graphite was fine-grained and was liberated at 400 mesh size.

Rougher flotation with 100 mesh feed followed by four cleanings produced a grade of 82.5% FC with 21.2% FC distribution in it. Regrinding of the rougher concentrate followed by four cleanings yielded a grade of 85.0% FC and 6.5% ash with 43.0% FC distribution in it.

Pilot Plant tests

Pilot Plant tests were conducted with a composite sample as mentioned earlier. The composite sample analysed as follows:

Constituent	*Assay %*
Fixed Carbon	14.7
Ash	72.1
Volatile matter	12.0
CaO	14.0
MgO	2.5
CO_2	15.2
Fe in ash	3.1

Preliminary flotation test with 28 mesh feed followed by regrinding to 100 mesh and four cleanings yielded a grade of 85.1% FC and 10.3% ash with 69.2% FC distribution.

The R.O.M. ore was crushed in jaw crusher to 50 mm and then in a gyratory crusher that operated in closed circuit with a vibrating screen to 25 mm size. The crushed ore was ground in a 183 cm x 91.5 cm ball mill operating with a rake classifier. The classifier over-flow (50% —200 mesh) was conditioned and then sent to a battery of 12 nos. No. 8 Denver sub—A flotation cells (2.75 cu. ft. cap. each). Sodium silicate was added at the classifier over flow lip and pine oil at the conditioner discharge. The tailing was rejected and the concentrate was thickened in a 488 cm. dia thickener and reground in open circuit rod mill. The reground feed was floated in a battery of 3 nos. No. 7 Denver sub—A cell (1.5 cm. ft. Vol. each). The concentrate was further cleaned thrice in similar cell batteries. The cleaner tails were sent for thickening and regrinding. The final concentrate of the pilot plant tests analysed 84.2% FC and 10.4% ash with 78.5% FC distribution in it.

F Graphite from Gujarat:

A low grade graphite sample drawn from Jhab-Redhana area was received from the Gujarat Min. Dev. Corpn., for beneficiation studies. The sample consisted lumps upto 75 mm down to fines and analysed as follows :

Constituent	*Assay %*
Fixed Carbon	7.10
Ash	80.00
Volatile matter	11.29
Moisture	1.65
S	0.47
Fe in ash	3.65
Cu	0.10
Al_2O_3	18.90
CaO	15.19
MgO	2.52
CO_2	19.48

Mineralogical examination of the sample revealed that very fine grained graphite was associated with calcite quartz, felspars, mica etc. Liberation of graphite was not complete even at 200 mesh size.

The rougher graphite concentrate produced under the optimum conditions of 64.5% —200 mesh grind, 1.5 kg/tonne of sod. silicate, and 0.12 kg/tonne of

pine oil analysed 66.5% ash with 19.5% ash distribution. Rougher concentrate after three cleanings was reground to 89% —325 mesh and then followed by four more cleanings using 1.2 kg/tonne of sod. silicate, 0.08 kg/tonne of Katha and 0.11 kg/tonne of pine oil analysed 46.8% FC and 40.7% ash with 27.1% FC distribution. Instead, with only four cleanings only of the rougher float regrinding as in the above case, the concentrate analysed 41.65% FC and 38.6% ash with 76.6% FC distribution in it. This may be used in the foundry.

G Graphite from Madhya Pradesh

Two low grade graphite samples were received from the State Directorate of Mining and Geology, M.P. Actually both samples looked like coal samples and contained coal particles tending towards graphitisation.

1) Graphite from Chamua, Sidhi Dist.

The sample consisted of 75 mm lumps down to fines and analysed as follows :

Constituent	*Assay %*
Fixed Carbon	7.67
Ash	85.41
Volatile matter	5.11
Moisture	1.81
S	4.65
Fe in ash	2.65

Microscopic examination revealed that graphitised carbonaceous matter was found in association with quartz and minor amounts of pyrite, melnicovite, chlorite, biotite etc. Quartz was liberated at 150 mesh size, but the other argilaceous matter was liberated at 400 mesh size only.

Rougher flotation tests employing 87% —200 mesh grind, 0.6 kg/tonne of kerosene oil, 0.3 kg/tonne of pine oil and some soap nut extract solution yielded a concentrate assaying 68.82% ash with 18.2% ash distribution. After regrinding to 100% —200 mesh size followed by four cleanings, the concentrate analysed 49.21% ash with 2.5% ash distribution. Due to incomplete graphitisation, any useful grade of graphite concentrate cannot be produced from the sample.

2) Graphite from Gidhar, Sidhi Dist.

The sample was very much similar to Chamua graphite and analysed as follows :

Constituent	*Assay %*
Fixed Carbon	4.86
Ash	87.34
Volatile matter	6.69
S	0.69
Fe in ash	3.30

Rougher flotation concentrate produced with 87.0% —200 mesh grind, 0.5 kg/tonne kerosene oil, 0.5 kg/tonne of pine oil analysed 74.1% ash with 13.99% ash distribution. After two cleanings, the concentrate analysed 63.1% ash with 2.42% distribution. When the rougher concentrate was ground to 98% —200 mesh with 1.0 kg/tonne of sod. silicate, and after four cleanings the concentrate analysed 57.3% ash with 1.8% ash distribution. As the sample was composed of partly graphitised carbonaceous matter no graphite concentrate of any acceptable grade could be produced.

H Graphite from Kashmir

A low grade graphite from Braripura area in Baramulla Dist., was received through the Director, Mining & Geology Dept. The sample was composed of 100 mm lumps and some fines and analysed as follows :

Constituent	*Assay %*
Fixed Carbon	14.68
Ash	80.30
Volatile matter	4.16
Moisture	0.86

Mineralogical examination revealed that shale followed by quartz, felspar, kaolinite, calcite, mica etc. were the gangue minerals associated with the very fine grained amorphous graphite present in the sample. The nature of the ore indicated the difficulty in producing a high grade concentrate.

Rougher concentrate produced under the optimum conditions of flotation with 87% —200 mesh grind, 2.0 kg/tonne of sod. silicate, 0.2 kg/tonne of light diesel oil and 0.2 kg/tonne of pine oil, analysed 68.92% ash with 34.0% ash distribution in it. Rougher

flotation in acid and alkaline media did not show any improvement. After three cleanings with 1.75 kg/tonne of sod. silicate, the concentrate analysed 35.9% FC, 59.4% ash with 20.6% FC distribution in it. Further attempts to improve the grade were not successful.

I. Graphite from Kerala:

The sample from Attipara, Trivandrum, was received through the Director of Mines and Geology for beneficiation studies. The sample was composed of 75 mm lumps to fines and analysed as follows:

Constituent	*Assay %*
Fixed Carbon	59.84
Ash	35.47
Volatile matter	4.52
Moisture	0.17

Microscopic examination of the sample indicated that quartz and Kaolinized felspars followed by minor amounts of mica composed the gangue. Graphite was liberated from the gangue at below 65 mesh size.

Rougher graphite concentrate produced under optimum conditions of flotation with 17% —200 mesh grind 1.0 kg/tonne of sod. silicate, 0.12 kg/tonne of pine oil and 0.06 kg/tonne of light diesel oil, analysed 18.31% ash with 38.1% ash distribution in it. After two cleanings with 1 kg/tonne of sod. silicate and 0.08 kg/tonne of pine oil, the concentrate analysed 92.34% FC, 6.0% ash with 81.8% FC distribution in it.

Treatment of the rougher flotation concentrate on shaking tables yielded a graphite concentrate (lighter portion i.e. table tails) analysing 93.29% FC with 85.0% FC distribution, 4.95% ash and 1.76% VM + Moisture.

Straight tabling tests with the sample ground to 17% —200 mesh i.e. flotation feed produced a graphite concentrate analysing 89.28% FC with 79.3% FC distribution, 8.84% ash and 1.88% VM and moisture.

J. Graphite from Karnataka:

A low grade graphite from the Ganacharpur mines in Kolar area was received through the Bureau of Mineral Development, Mysore. The sample consisted mostly of fines and occasional lumps upto 25 mm in size. Complete analysis of the sample was as follows:

Constituent	*Assay %*
Fixed Carbon	12.08
Ash	80.66
VM+Moisture	7.26

Quartz, mica, ochre, clay and minor quantity of tourmaline composed the gangue. Rougher concentrate produced under optimum conditions of 73.8% —200 mesh grind, 1.0 kg/tonne of sod. silicate, 0.08 kg/ tonne of pine oil analysed 61.16% ash with 14.4% ash distribution. After one cleaning with 1.0 kg/tonne of sod. silicate, the concentrate analysed 43.00% FC with 25.8% FC recovery and 51.52% ash.

K. Graphite from Bhutan:

A low grade graphite sample drawn from Khepanshi hill was received from the Director, GSI-Bhutan circle for beneficiation. The sample was composed of fines and lumps upto 100 mm in size and analysed as follows:

Constituent	*Assay %*
Fixed Carbon	10.66
Ash	86.40
Volatile matter	2.94
Moisture	0.66
Fe in ash	1.70
S	0.18
P_2O_5	0.03
TiO_2	1.10

Mineralogical examination revealed that quartz and micas formed the bulk of the gangue followed by sillimanite, and andalusite, rutile, apatite, goethite etc. Graphite was very fine grained and complete liberation was quite difficult.

Rougher flotation tests with a feed ground to 325 mesh size with 0.06 kg/tonne of sod. silicate produced a concentrate analysing 52.71% ash with 23.8% ash distribution in it. After three cleanings with 0.3 kg/tonne sod. silicate, the concentrate analysed 63.4% FC with 78.6% FC distribution and 33.3% ash with 5.1% ash distribution, which may be used in the foundry and paint industries.

The condensed results of the various graphite samples tested are given in the following Table 5.2.

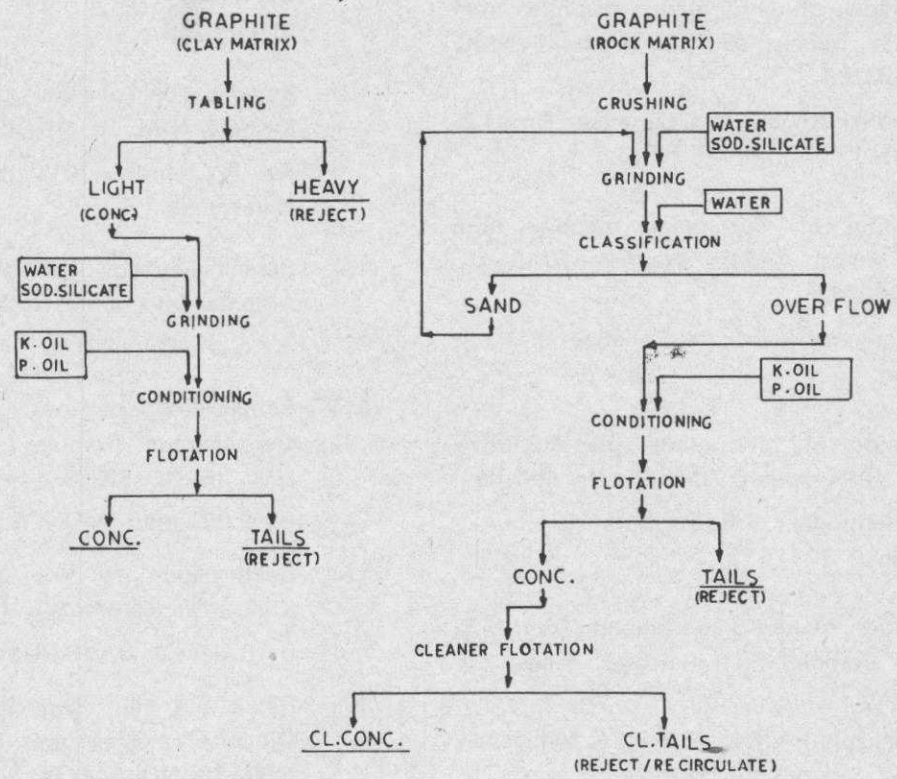
TABLE 5.2—BENEFICIATION TESTS ON GRAPHITE ORE SAMPLES

State & Locality	Feed Assay%	Beneficiation method	Conc. Assay %	Conc. Recovery %	Remarks
I. Andhra Pradesh:					
(1) Khammam Dist.	19.7 FC 71.7 ash	Rougher flotation regrinding and two cleanings.	77.8 FC 17.5 ash	36.34 FC 2.3 ash	
(2) Gangavaram	19.38 FC	Calcination at 950°C, roughing regrinding and four cleanings.	79.47 FC 18.24 ash	6.4 ash	
(3) Erramettala	21.8 FC 67.10 ash	Calcination, rougher flotation, regrinding and 3 cleanings.	74.24 FC 24.19 ash	1.45 ash	
(4) Sitapalli	17.00 FC 79.79 ash	Rougher flotation, regrinding and four cleanings.	87.35 FC 10.49 ash	67.18 FC	
(5) Khammam, APIDC.	22.8 FC 67.8 Ash	Flotation :	69.2 FC	50.0 FC	
IR. NO. 886/76.	7.3 V.M. 0.5 CaO 2.1 S				
II. Assam:					
Lohit Dist NEFA	2.15 FC 95.75 ash	Rougher flotation, regrinding and four cleanings.	45.13 FC 51.0 ash	46.2 FC 1.1 ash	
III. Orissa:	77.85 FC 17.60 ash	Rougher flotation regrinding and three cleanings.	90.0 FC 6.4 ash	99.0 FC 29.8 ash	For use in battery industry.
IV. Bihar:					
Palamu	15.5 FC 76.2 ash	Rougher flotation, regrinding and four cleanings.	88.0 FC 6.5 ash	90.8 ash	For use in battery industry.
V. Rajasthan:					
Lotiyana	2.17 FC 84.03 ash	Flotation	—	—	Not possible to concentrate.
Doomara	8.19 FC 84.37 ash	Rougher flotation and 1 cleanings.	56.65 ash	3.5 ash	
R.S.M.D.C.	5.83 FC 81.87 ash	Rougher flotation, regrinding and six cleanings.	86.26 FC 8.37 ash	76.1 FC	

TABLE 5.2—BENEFICIATION TESTS ON GRAPHITE ORE SAMPLES *(Contd.)*

Sample & Locality	Assay % R.O.M./As received	Beneficiation Method/Process	Final conc. Assay %	Product Recovery %
1	2	3	4	5
Graphite from Banswara Rajasthan from RSIDC. IR. NO. 844/75 Batch & Pilot Plant Studies.	**Tantia Sample:** FC = 16.32% Ash = 68.46% VM = 13.53% CaO = 12.68% MgO = 0.73% CO_2 = 10.12% Moisture = 1.28%	**Rougher flotation:**	FC = 32.0%	98.2% FC
		After two cleanings	FC = 60.8%	44.3% FC
		Rough flotation, regrinding & 4 cleanings — 65 mesh	FC = 86.1%	77% FC
		,, —100 mesh	FC = 88%	72.4% FC
	Sasakota sample: FC = 13.09 VM = 11.48 Ash = 75.46 CaO = 17.14 CO_2 = 19.21 MgO = 5.21	**Flotation:** Followed by regrinding to 100 mesh and 4 cleanings.	FC = 84.1%	64.5% FC
		—100 mesh grind with 4 cleanings.	FC = 81.5%	60.1% FC
	Kesharapura sample: FC = 6.36 Ash = 77.0 VM = 15.36 CaO = 20.0 MgO = 5.8 CO_2 = 3.92	**Rougher flotation:** Regrinding and 4 cleanings.	FC = 82.5% FC = 85%	21.2% FC 43.0% FC
Pilot Plant Studies	**Composite sample:** FC = 14.7 Ash = 72.1 VM = 12.0 CaO = 14.0 MgO = 2.5 CO_2 = 15.2	**Pilot Plant Studies** Gring = —28 mesh; Regrind to —100 mesh and 4 cleanings.	FC = 85.1%	69.2% FC
		Final concentrate.	FC = 84.2%	78.5% FC

VI. **Karnataka:**					
Ganacharpur	80.66 ash 12.08 FC	Rougher flotation followed by one cleaning.	43.00 FC 51.42 ash	25.8 FC 4.4 ash	
VII. **Gujarat:**					
Jhab-Redhana	7.10 FC 80.00 ash	Rougher flotation, regrinding and four cleanings.	46.8 FC 40.7 ash	27.1 FC	
VIII. **Madhya Pradesh:**					
Chamua	7.67 FC 85.40 ash	Rougher flotation, regrinding and four cleanings.	49.21 ash	2.5 ash	In complete graphitization not possible.
Gidhar	4.86 FC 87.34 ash	,,	57.3 ash	1.8 ash	,,
IX. **Kashmir:**					
Bararipurra	14.68 FC 80.30 ash	Rougher flotation and 3 cleanings.	35.9 FC 59.4 ash	20.6 FC	
X. **Kerala:**	59.84 FC 35.59 ash	Rougher flotation and 2 cleanings.	92.34 FC 6.00 ash	81.8 FC	
		Rougher flotation followed by tabling.	93.25 FC 4.95 ash	85.0 FC	
XI. **Bhutan:**					
Khepanshi	10.66 FC 86.40 ash	Rougher flotation followed by three cleanings.	63.4 FC 33.3 ash	78.6 FC 5.1 ash	



K.OIL - KEROSENE OIL
P.OIL - PINE OIL

Fig. 5.1—General Flowsheet for Beneficiation of Graphite

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MOLYBDENITE

Molybdenite occurs as a mineral associate of economic importance in the copper ore deposits of Singhbhum district. Recently low grade molybdenite deposits were located at Karadikuttam area of Madurai Dist. in Tamil Nadu.