

Concentration of Indian Chrome Ores by Ore-dressing Methods

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Low-grade chrome ores (roughly classified: simple, ferruginous, chrome spinel) from different parts of India were subjected to beneficiation studies at National Metallurgical Laboratory, to determine their amenability to concentration by ore-dressing methods. Simple ores could easily be concentrated by common gravity methods like tabling and Humphrey's spiral, but the chromium/iron ratio in most cases was low due to iron being present in chemical combination in the mineral chromite. Ferruginous ores were subjected to reduction roast and magnetic separation, and high-grade concentrates low in iron—ideal for ferro-chrome, could be produced. Chrome spinels could not be beneficiated to any appreciable extent.

CHROMITE, also known as chrome ore, is the only commercial source of the metal chromium. It is a mineral of the spinel group and occurs in ultrabasic rocks. It ranks high as a strategic mineral both during war and peace time, being chiefly used for producing ferro-chrome for use in stainless and other alloy steels in metallurgical industries, for making refractory bricks and for manufacturing sodium and potassium dichromates etc. in chemical industries. Chromium salts are used for electroplating, tanning, pigments, photography, dyeing, glass making and other miscellaneous purposes.

The chromite reserves of India are sufficient to meet the country's requirements. The deposits of Mysore and Bihar have been worked since 1907 and 1913 respectively. And more have since been discovered in other parts of the country. Its small consumption in the country is limited to chemical and refractory industries; the rest of the production is exported. Its mining is selective and confined only to high-grade ores which can be hand picked. Low-grade deposits requiring beneficiation are not worked on any appreciable scale.

Laboratory studies on beneficiation of low-grade Indian chrome ores were first taken up by the utilization branch of the Geological Survey of India during the last War and some low-grade samples collected from different parts of India were beneficiated employing jigging, tabling, magnetic separation and flotation. In 1950, at the instance of the Metals Committee, the National Metallurgical Laboratory having a well-equipped ore-dressing division undertook a systematic study of the amenability of Indian low-grade ores to beneficiation. Since then, ten low-grade samples from different mines situated in the States of Mysore, Bihar and Orissa have been inves-

tigated at the Laboratory. The present paper briefly outlines the results obtained with the various samples.

MINERALOGY

Chromite is represented by the formula $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ and has the theoretical composition of 68% Cr_2O_3 and 32% FeO . It is rarely found in the pure state and is essentially $(\text{Fe Mg})\text{O} \cdot (\text{Cr Al Fe})_2\text{O}_3$. The iron is partly replaced by magnesium, and the chromium by aluminium and ferric iron. Naturally occurring chromite seldom contains more than 55% Cr_2O_3 .

Chromite varies in colour from jet black to brownish black and usually occurs in granular, compact or massive forms, although individual crystals are octahedral. It is rather soft and has a hardness of 5.5 on Moh's scale. It has a specific gravity varying from 4.0 to 4.6 according to the grade of ore. Its melting point varies with its composition in the range 1545 to 1730°C. It has a lustre approaching that of metals and is almost insoluble in acids. It is usually feebly magnetic and gives a brown streak on unglazed porcelain.

OCCURRENCE

Chromite deposits are generally magmatic segregations and are found in ultrabasic igneous rocks like peridotites, pyroxenites, amphibolites or dunites and their alteration products such as serpentine, talc or talc chlorite schists. Chromite occurs in the host rock as masses, lenses and disseminations. In some places, the disseminated grains have been converted into workable ore bodies, by residual concentration. Alluvial deposits formed by transportation of chromite grains by water are also known.

USES

The industrial uses of chromite fall into three

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TABLE I—SPECIFICATIONS OF CHROMITE

Metallurgical	Refractory	Chemical
Cr ₂ O ₃ — 48.0 per cent (min)	Cr ₂ O ₃ — 38-48	Cr ₂ O ₃ — 40.0 per cent (min)
Cr/Fe ratio — 2.8 (min)	Al ₂ O ₃ — 12-24	Cr/Fe ratio — 1.6 (min)
SiO ₂ — 5.0 per cent (max)	Fe ₂ O ₃ — 14-24	SiO ₂ — 5 per cent (max)
Alumina +		
Magnesia — 25.0 per cent (max)	MgO — 14-13	
S — 0.5 per cent (max)	SiO ₂ — upto 10	
P — 0.2 per cent (max)		

main groups, namely, metallurgical, refractory and chemical.

The ore finds its largest single use in the manufacture of ferro-chrome. Addition of chromium improves the strength, corrosion and oxidation resistance of iron, nickel and other metals.

For refractory purposes chromite is mostly used for making chrome and chrome magnesite bricks. Ramming mixtures made from chrome ores have also been developed and used for furnace bottoms and, in the finely ground conditions, it is used for patching furnace walls. Chromite is chemically neutral and it resists attack by both acids and bases at high temperatures.

For chemical industries, chromite is mostly used for the manufacture of chromates, dichromates, chromic acid, chrome-alum, etc.

The specifications of chromite for the various industries are given in Table I.

Analyses of chromite used by the Tata Iron and Steel Co. Ltd. for manufacture of refractories are given in Table II.

TABLE II.

High-grade Ores for Chrome Bricks		Low-grade Ores for Chrome-Magnesite Bricks	
	Per cent		Per cent
Cr ₂ O ₃	— 45-50	Cr ₂ O ₃	— 35-40
Fe ₂ O ₃	— 15-20	Fe ₂ O ₃	— 15-24
SiO ₂	— 4-8	SiO ₂	— 10-16
Al ₂ O ₃	— 8-10	Al ₂ O ₃	— 8-10
MgO	— 8-12	MgO	— 8-12

DISTRIBUTION IN INDIA

The important chromite deposits, which are at present worked, are situated in Hassan and Mysore districts in Mysore, Keonjhar and Cuttack districts in Orissa, and Singhbhum district in Bihar. Other occurrences are known in Salem district of Madras, Ratnagiri district in Bombay, Chitaldrug district in Mysore, Krishna district in Andhra, and in Kashmir and Andaman Islands. No reliable data are available on India's reserves. Much remains to be done in regard to proving and assessing the deposits. A rough estimate however, places the reserves at 1,320,000 tons.

Mysore.—Disseminations of chromite occur in several places in serpentinized ultrabasic rocks of Mysore, large workable ore bodies are found in the districts of Hassan and Mysore. In Hassan district,

there are several deposits in the ultrabasic intrusions (largely altered to talc and serpentine) in the Nuggihalli schist belt, which extends over a length of 35 miles and has a width of half a mile. Most of these are of low grade containing less than 42% Cr₂O₃. The best deposits are found in Byrapur and Bhaktarhalli. This district is at present the principal producer of chromite in India. The reserves are estimated at about half a million tons. In Mysore district, the deposits lie between Mysore and Nanjangud, specially to the west of Kadakola. The principal ores occur at Sinduvalli. The dunite rock here is traversed by lenses and veins of chromite and also by a net work of magnesite.

Several low-grade deposits are known in Kodur and Chitaldrug districts also.

Orissa:—Important deposits of chromite occur in an area of about 700 acres, near the village Nausahi in Keonjhar district. The chromite forms Schlieren bands, massive lenses and disseminations in serpentine, derived from peridotite. Some of the representative samples on analysis yielded a Cr₂O₃ content over 52 per cent and a Cr/Fe ratio over 3 and hence some of the deposits may yield ore of suitable quality for metallurgical use. Low-grade lateritic type of ores are also present.

Several lodes of low-grade chromite also occur in Cuttack district.

Bihar.—Chromite is found in Singhbhum district in three separate occurrences of peridotitic rocks (largely serpentinized) near Jojo Hatu, of which the deposits on the hills of Roro and Chitung are the most important. Chromite occurs as segregations and also as veins, the veins being lenticular in shape, up to 100 ft. long and 3 ft. thick. High-grade ores with Cr₂O₃ content of about 53 per cent are obtained but considerable amount of low-grade ores are also found.

India's chromite production and exports during the past seven years are shown in Table III.

The indigenous consumption is not high and most of the chromite produced are exported. In India there is no production of ferro-chrome.

BENEFICIATION

The grade of a chromite ore depends upon two factors: (i) the amount of gangue present in the ore, and (ii) the chemical composition of the chromite itself. The free gangue usually associated with

TABLE III

Year	India s Production	India s Export	World Production
1947	34,717	37,615	1,598,000
1948	22,555	9,250	1,943,000
1949	19,416	6,382	2,130,000
1950	16,729	3,864	2,305,000
1951	16,702	8,838	2,750,000
1952	35,187	8,936	3,300,000
1953	64,770	15,357	3,530,000
1954	45,507	23,353	3,240,000

it can be removed by mechanical means like dressing, but if the chromium content in the mineral chromite is itself low, mechanical methods of dressing will not be able to produce a concentrate of the required specification. Such ores may be treated by roasting, leaching etc. The present paper confines itself only to the application of ore-dressing techniques to the chrome ores investigated in the ore-dressing division of the National Metallurgical Laboratory.

Samples from Bihar.—Two samples of low-grade chromite from Kittaburu, Singhbhum district, Bihar, were received (from the Tata Iron & Steel Co. Ltd.) for beneficiation studies. The samples were mostly in lumps and were termed hard and soft ore according to the gangue present in them. Liberation of chromite from the gangue minerals occurred between -28 to -65 mesh indicating that simple gravity methods could be employed for concentrating the samples.

Kittaburu soft ore.—The principal gangue minerals present in the Kittaburu soft ore sample were chlorite, talc, and dolomite with minor amounts of magnesite, magnetite and limonite. The liberation of chromite from the gangue minerals occurred at about -65 mesh. Jigging, tabling and Humphrey's spiral tests were employed with the sample. The summary of the results obtained by the various methods of concentration are given in Table IV.

Kittaburu hard ore.—Serpentine, asbestos and

magnetite were the principal gangue in the Kittaburu hard ore sample and chromite was found to be fairly liberated at -10 mesh and completely liberated at -28 mesh.

Jigging, tabling, Humphrey's spiral, magnetic separation and flotation tests were conducted with the sample. A summary of the results obtained by various methods of concentration is given in Table V.

Kittaburu samples yielded good grade concentrates with high recoveries ideal for chemical and refractory industries. However, the chromium to iron ratios of the concentrates could not be raised to make it suitable for the production of ferro-chrome. The Tata Iron and Steel Co. Ltd. have installed a plant in this area for concentrating the above ores by tabling.

Samples from Mysore.—In all, five samples from Dodkanya, Dodkatur, Arsekere, Talur and Byrapur from the Mysore State were beneficiated. The first four samples were received from the Tata Iron and Steel Co. Ltd., and the last one from the Government of Mysore.

Dodkanya.—The Dodkanya Ore contained chlorite, magnesite, limonite, magnetite and calcite as the principal gangue and the liberation of chromite occurred only at -100 mesh. Tabling the sample at -100 mesh produced the best method which are presented in Table VI.

Dodkatur.—The principal gangue minerals in the Dodkatur sample were serpentine, talc, bastite, calcite, tremolite and quartz. Chromite was fairly liberated from the gangue at -65 mesh, though a portion of it remained interlocked even at -150 mesh.

Tests comprising tabling, Humphrey's spiral and magnetic separation were carried out with the sample and the results are summarized in Table VII.

The grade of chromite concentrate was low, because the chromite mineral itself was of low-grade, with its high iron and alumina contents. It may even be termed a chrome spinel.

Talur.—The Talur sample consisted of magnesite, serpentine, calcite, augite, olivine, hypersthene and hornblende as the principal gangue. Liberation of chromite from the gangue minerals took place at

TABLE IV.—COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS OF CONCENTRATION

Original sample : Cr_2O_3 , 36.66 ; FeO, 19.05 ; MgO, 14.26 ; Al_2O_3 , 4.7 ; SiO_2 , 17.06 and CaO 4.49 per cent.

Tests	Particulars	Assay per cent		Distribution %	
		Cr_2O_3	FeO	Cr_2O_3	Cr/Fe
Jigging and tabling	Jigging of -14+48 mesh fraction followed by tabling of -48 mesh fraction (including jig tailings)	48.3	20.84	75.9	—
Straight tabling	Tabling at -65 mesh after classification	54.1	22.4	71.6	2.1
Humphrey's spiral	Sample ground to -48 mesh and treated in spiral	50.36	—	55.5	—

Best grade of concentrate : Cr_2O_3 , 54.1 ; FeO, 22.4 ; Al_2O_3 , 7.12 ; MgO, 11.12 ; and SiO_2 , 3.92 per cent.

TABLE V.—COMPARISON OF RESULTS OBTAINED BY VARIOUS METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 34.97 ; FeO, 17.75 and SiO₂, 14.9 per cent.

Tests	Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Jigging and tabling	Jigging of -10+28 mesh fraction followed by tabling of -28 mesh fraction	51.23	22.5	82.8	2.0
Straight tabling	Tabling at -48 mesh after classification	50.72	—	85.5	—
Humphrey's spiral and tabling	Spiral treatment of the sample at -48 mesh followed by tabling of the spiral mid- dling at -65 mesh	50.17	—	84.4	—

Best grade of concentrate : Cr₂O₃, 51.23 ; FeO, 22.5 ; Al₂O₃, 9.65 ; and MgO, 11.3 per cent.

TABLE VI—TABLING OF -100 MESH SAMPLE

Original sample : Cr₂O₃, 29.42 ; FeO, 16.0 ; MgO, 17.38 ; Al₂O₃, 10.05 and SiO₂, 10.16 per cent.

Product	Weight %	Assay per cent						Distribution % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO	MgO	Al ₂ O ₃	SiO ₂	CaO		
Table conc. 1.	43.8	47.5	23.5	10.5	14.94	1.49	2.54	70.6	1.7
Table conc. 2.	3.1	42.2	20.7	—	—	—	—	4.4	—
Table tailing	25.2	10.01	8.0	—	—	—	—	8.6	—
Slime	27.9	17.29	10.84	—	—	—	—	16.4	—
Feed	100.0	29.5	15.7	—	—	—	—	100.0	—

TABLE VII—COMPARISON OF RESULTS OBTAINED BY DIFFERENT METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 26.29 ; FeO, 20.42 ; and SiO₂ 11.51 per cent.

Tests	Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling	Straight tabling at -65 mesh	38.86	28.86	76.1	1.2
Humphrey's spiral	Spiral treatment at -65 mesh	39.66	—	65.8	—

Best grade of concentrate : Cr₂O₃, 38.86 ; FeO, 28.86 ; Al₂O₃, 16.75 ; CaO, 1.69 ; MgO, 12.03 ; SiO₂, 1.31 ; S, 0.07 per cent and P, trace.

TABLE VIII—RESULTS OBTAINED BY VARIOUS METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 35.21 ; FeO, 20.42 ; and SiO₂ 11.51 per cent

Tests	Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling	Tabling after grinding to -65 mesh	48.67	21.62	81.2	1.9
Spiral and tabling	Humphrey's spiral treatment at -48 mesh followed by tabling of the concentrate	46.67	—	73.8	—
Flotation	Flotation using "Armeen S" as frother collector	44.27	—	68.5	—

Best grade of concentrate : Cr₂O₃, 48.67 ; FeO, 21.62 ; MgO, 12.25 ; Al₂O₃, 13.99 ; SiO₂, 0.85 ; S, 0.10 ; and P, 0.11 per cent.

-48 mesh and tabling, Humphrey's spiral, magnetic separation and flotation tests were carried out with the sample. The results obtained by the various methods of concentration are given in Table VIII.

Arsekere.—Antigorite, chlorite, talc and anthophyllite were the principal gangue minerals present in the Arsekere sample. Chromite was found to be liberated from the gangue minerals at -65 mesh. Tabling, Humphrey's spiral, magnetic separation and flotation tests were carried out with sample. The results of different tests are reported in Table IX.

Byrapur.—The Byrapur sample contained mag-

nesite, serpentine, ochre and quartz as the chief gangue minerals and complete liberation of chromite occurred at 65 mesh. The sample was subjected to tabling, Humphrey's spiral and magnetic separation tests. The results of various methods of concentration are shown in Table X.

Mysore concentrates were comparatively higher in iron than those from Bihar, even after beneficiation the chromium iron ratio in the former being below 2:1. The concentrates were therefore unsuitable for the manufacture of ferro-chrome but could be used in refractories and chemical indus-

TABLE IX.—RESULTS OBTAINED BY VARIOUS METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 29.47 ; and FeO, 17.65 per cent.

Tests	Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling Humphrey's spiral Flotation	Straight tabling at -100 mesh	47.97	27.66	75.6	1.5
	Spiral treatment at -65 mesh	44.2	—	64.8	—
	Sample ground to 67% -200 mesh and deslimed	46.0	—	75.1	—
Reagents : 3.0 lb./ton H ₂ SO ₄ 0.5 lb./ton Sodium oleate 1.0 lb./ton Oleic acid					
Best grade of concentrate : Cr ₂ O ₃ , 47.97 ; FeO, 27.66 ; Al ₂ O ₃ , 10.57 ; MgO, 9.29 ; SiO ₂ , 3.04 ; CaO, 0.88 ; P, 0.03 and S, 0.13 per cent.					

TABLE X—BEST RESULTS OBTAINED BY VARIOUS METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 36.74 ; FeO, 22.93 ; MgO, 15.47 ; CaO, 0.65 ; Al₂O₃, 6.22 and SiO₂, 12.36 per cent.

Tests	Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling	Tabling at -48 mesh after classification	48.84	28.12	88.5	1.5
Humphrey's spiral and tabling	Spiral treatment of sample at -48 mesh followed by tabling of spiral middling	47.78	—	80.0	—
Magnetic separation	Sample crushed to -65 mesh deslimed and passed through the magnetic separator at high intensity	49.08	29.18	90.6	1.5
Best grade of concentrate : Cr ₂ O ₃ , 48.84 ; FeO, 28.12 ; SiO ₂ , 3.84 ; Al ₂ O ₃ , 8.26 ; MgO, 8.2 ; CaO, 1.15 ; and P, 0.03 per cent.					

tries. The Mysore Chromite Ltd. have been concentrating small quantities of chromite by tabling.

Samples from Orissa.—Two samples from Nausahi, in the Keonjhar district, and a third from Gunjang chromite mine in the Cuttack district, were beneficiated.

Boula mine.—The Boula sample was received from Mr. E. H. Tullock. It contained talc, serpentine and anthophyllite as the principal gangue. Liberation of chromite from the gangue occurred at -35 mesh.

Tabling, Humphrey's spiral, magnetic separation and flotation methods were employed with the sample. The results obtained by different methods of concentration are summarized in Table XI.

The Cr/Fe ratio of the concentrates is higher than those obtained with Mysore and Bihar ores, though not suitable for production of standard ferrochrome.

Nausahi.—The Nausahi sample was received from Messrs. Serajuddin & Co. Talc, serpentine and anthophyllite were the principal gangue minerals present in the sample. Chromite was found to be liberated from the gangue minerals at -65 mesh. Tabling, Humphrey's spiral, magnetic separation and flotation tests were employed with the sample. The results obtained by different methods of concentration are given in Table XII.

The Cr/Fe ratio in the concentrate is even better than those obtained with the earlier sample from Nausahi.

Gunjang chromite mine.—In all the nine samples reported so far, the iron was present in chemical combination with the chromite, and consequently these could not be reduced by common ore-dressing methods. In the Gunjang sample the iron mineral was present in the form of hydrated iron oxide. The sample from Gunjang chromite mine, Cuttack district, Orissa, was received from Mr. Aikath of Chai-bassa. The sample was brownish in colour due to the presence of limonitic ochre. The chromite grains were embedded in a matrix of hydrated iron oxide. The sample as received assayed Cr₂O₃, 41.4 ; acid insoluble iron expressed as FeO, 8.8 ; acid soluble iron expressed as Fe₂O₃, 28.2 ; MgO, 8.6 ; Al₂O₃, 7.9 ; and SiO₂, 1.2 per cent. The acid soluble iron was present as free iron oxide and it was the principal impurity in the sample. Microscopic examination of the crushed sample showed that the chromite was free from the gangue below 48 mesh. Straight magnetic separation did not produce any encouraging results. Gravity methods could not be applied due to the small difference in specific gravity between the gangue and the chromite. Magnetizing reduction process which had proved to be very efficient in the beneficiation of ferruginous manganese ores, was employed with success with this ore also.

The method consists of converting the iron oxide to magnetite and removal of the magnetite by magnetic separation, leaving a non-magnetic product containing most of the chromite. The gas for reduc-

TABLE XI—RESULTS OBTAINED BY DIFFERENT METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 44.7 ; FeO, 17.18 ; MgO, 15.33 ; SiO₂, 13.48 ; Al₂O₃, 7.9 ; CaO, 0.55 ; and P, 0.04 per cent.

Tests	Description	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling	Tabling at -35 mesh after classification	53.11	19.89	94.4	2.3
Humphrey's spiral	Spiral treatment at -48 mesh	54.11	20.52	79.6	2.4
Magnetic separation	Magnetic separation at -48 mesh	54.69	20.33	87.9	2.4
Flotation	Sample ground to 48.3% -200 mesh and deslimed	53.5	20.3	85.7	2.3
Reagents : 0.5 lb. ton soda ash 2.2 lb. ton sodium sulfonate 9.0 lb. ton sulphuric acid					
The best grade of concentrate assayed : Cr ₂ O ₃ , 53.11 ; FeO, 19.89 ; MgO, 13.27 ; Al ₂ O ₃ , 8.53 ; SiO ₂ , 3.5 ; CaO, 1.39 ; and traces of P.					

TABLE XII—RESULTS OBTAINED BY VARIOUS METHODS OF CONCENTRATION

Original sample : Cr₂O₃, 42.5 ; FeO, 16.62 ; Al₂O₃, 7.98 ; MgO, 15.44 ; SiO₂, 14.24 and P, 0.51 per cent.

Tests	Particulars	Assay percent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
		Cr ₂ O ₃	FeO		
Tabling	Tabling at -65 mesh after classification	55.4	19.4	91.7	2.5
Humphrey's spiral	Spiral treatment at -65 mesh	54.7	19.0	91.5	2.5
Magnetic separation	Sample ground to -35 mesh and passed through the magnetic separator	54.25	18.19	84.9	2.6
Flotation	Sample ground to 25.7% -200 mesh and deslimed	53.31	19.0	91.5	2.5
Reagents : 6.0 lb. ton sulphuric acid 3.0 lb. ton sodium sulfonate					
The best grade of concentrate assayed : Cr ₂ O ₃ , 55.4 ; FeO, 19.4 ; MgO, 13.02 ; Al ₂ O ₃ , 8.85 ; SiO ₂ , 3.2 and P, 0.07 per cent.					

tion of hematite or limonite to magnetite may be pure hydrogen or carbon monoxide or industrial gases like blast-furnace gas, coke-oven gas or producer gas. The size of the ore for reduction is not

TABLE XIII—RESULTS OBTAINED BY REDUCING ROAST FOLLOWED BY MAGNETIC SEPARATION.

Original sample : Cr₂O₃, 41.4 ; Acid insoluble iron expressed as FeO, 8.8 ; Acid soluble iron expressed as Fe₂O₃, 28.2 ; MgO, 8.6 ; Al₂O₃, 7.9 and SiO₂, 1.2 per cent.

Particulars	Assay per cent		Distribu- tion % Cr ₂ O ₃	Cr/Fe
	Cr ₂ O ₃	FeO		
Reducing roast of the sample at -3 mesh followed by magnetic separation at -65 mesh	58.3	17.3	86.4	3.0
Complete analysis of the concentrate : Cr ₂ O ₃ , 58.3 ; FeO, 17.3 ; MgO, 13.62 ; Al ₂ O ₃ , 3.81 ; SiO ₂ , 0.83 ; per cent and P, trace.				

critical provided there are not excessive amounts of fines. The optimum temperature for reduction of limonite and hematite to magnetite is 500-560°C. After reduction the ore was crushed to a size at which the iron minerals were liberated. The crushed material was passed through a magnetic separator and the intensity of the field was adjusted according to the grade of chormite desired.

Reducing roast of the Gunjang sample at -3 mesh followed by magnetic separation produced a chromite concentrate having a chromium to iron ratio of 3.0, ideal for the production of ferrochrome. The results are shown in Table XIII.

Compared to Bihar and Mysore ores the Orissa ores yielded better grade concentrates with high recoveries. The chromium to iron ratios varied from 2.5 to 3.0 so that they might be used for metallurgical industries either individually or after blending.

CONCLUSIONS

Indian chromite, in general, may be characterized by their high iron content which being present in chemical combination in the mineral chromite, cannot be reduced by ore-dressing methods. Some chrome ores of Orissa have a Cr/Fe ratio more than 3 and such ores should be carefully conserved for the metallurgical industry for production of standard ferro-chrome.

The concentrates obtained from Bihar and Orissa ores have chromium to iron ratios varying from 2.0 to 2.5 and can profitably be used only by the chemical and refractory industries, but not for production of standard ferro-chrome.

The concentrates obtained from the Mysore ores are comparatively poorer in grade and have very low Cr/Fe ratios varying from 1.1 to 1.9. For metallurgical purpose they may be used in two stages i.e. mechanical beneficiation followed by one of the following processes :

- (1) To make chrom-X, a trade name for low-grade ferro-chrome.
- (2) May be directly converted into stainless steel by the Wild process.
- (3) The concentrate may be subjected to chemical beneficiation like leaching.

Steel producers generally are accustomed to the use of standard-grade of ferro-chrome and hence the first two methods may only be applied in an emergency. Production in India of standard-grade ferro-chrome from high iron concentrates is therefore possible only by removal of some of the excess iron by chemical methods, followed by use of these low iron concentrates for ferro-chrome production. The present requirement of ferro-chrome is very small, as the production of alloy steel in the country is not appreciable. However, with the expansion of engineering industries such as automobiles, industrial plant and machinery etc., the requirement would increase. The demand for standard ferro-chrome for the next few years may not exceed 200-

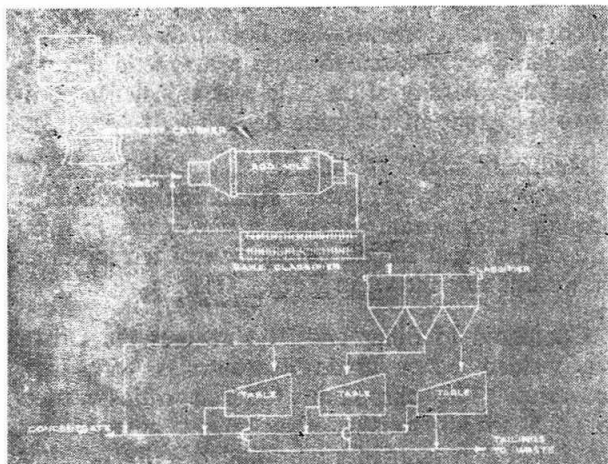


FIG. 1—Flow sheet for simple chrome ores.

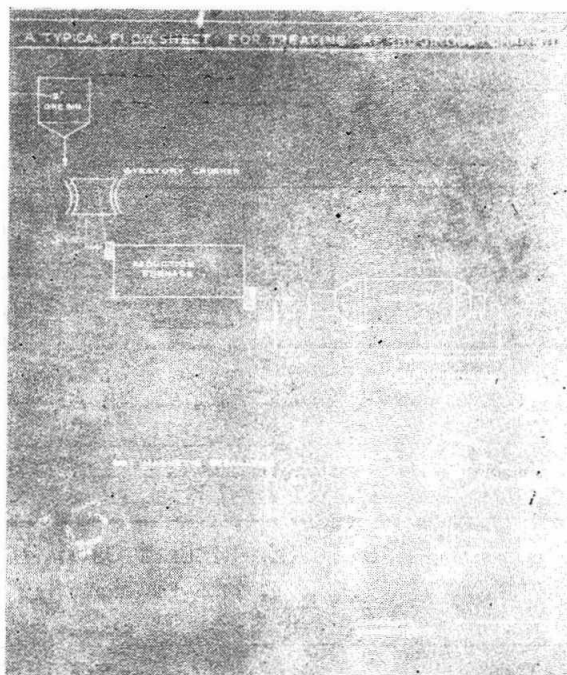


FIG. 2—Flow sheet for ferruginous chromite.

250 tons per year. The requirement would increase if stainless steel sheets, which are getting popular for the manufacture of household utensils, are to be produced in the country.

Figs. 1 and 2 are typical flowsheets for (i) simple and (ii) ferruginous chrome ores.

REFERENCES

1. ALLEN, R. and HOWLING, G. E. Chrome ores and chromium. Rep. on the Min. Res. Br. Empire and foreign countries, Imperial Institute, London, 1940.
2. KRISHNAN, M. S. Chromite. *Bull. Geol. Surv. India*. Ser. A. No 7 (1953).
3. JOHNSTON, SYDNEY, J. Minerals for the chemical and allied industries. Chapman & Hall, London, 1954.
4. NARAYANAN, P. I. A. and SEN, M. C. *J. Sci. Industr. Res.*, **11A** (1952), 207.
5. NARAYANAN, P. I. A. and BANERJEE, S. K. *J. Sci. Industr. Res.* **11A** (1952), 205.
6. NARAYANAN, P. I. A. and MATHUR, G. P. *J. Sci. Industr. Res.*, **11A** (1952), 202.
7. SEN, M. C. and NARAYANAN, P. I. A. *J. Sci. industr. Res.* **11A** (1952), 505.
8. BANERJEE, S. K. and NARAYANAN, P. I. A. *J. Sci. industr. Res.*, **12A** (1953), 136.
9. SEN, M. C. and NARAYANAN, P. I. A. *J. Sci. industr. Res.* **12A** (1953), 185.
10. SUBRAMANYA, G. V. and NARAYANAN, P. I. A. N.M.L. unpublished report No : IR 66/1955.
11. DAS GUPTA, S. B. and NARAYANAN, P. I. A. N.M.L. unpublished Report No : IR 83/1956.
12. BANERJEE, S. K. and NARAYANAN, P. I. A. N.M.L. unpublished Report No : IR 96/1956.
13. DHARMA RAO, P. and NARAYANAN, P. I. A. N.M.L. unpublished Report No : 100/1956.