Beneficiation and Processing of some Important Raw Materials for Iron and Steel Production

G. P. Mathur
P. I. A. Narayanan

THE paper deals with the beneficiation and processing of some of the important raw materials like iron ore, manganese ore, chromite, fluorspar, etc. used in the Iron and Steel Industry. Coal is not covered as this paper presents only the results obtained in the National Metallurgical Laboratory.

India is committed to a policy of industrialisation and, along with others, the mineral industries are also expanding. The iron and steel industry in the country can be considered to be fairly well established and with the expansion of the existing plants and the erection of three new plants, the steel ingot production is expected to go up to six million tons by the end of the Second Plan period. Four ferro-manganese plants in the country viz. (*i*) The Tata Iron and Steel Company's plant at Joda, (*ii*) Jeypore Mining Syndicate's at Raygada (Orissa), (*iii*) Ferro Alloys Corporation at Garividi (Andhra) and (*iv*) Electro Metallurgical Works Private Ltd., at Dandeli (Bombay) have gone into production and five more plants are expected to be established shortly to increase the production to 1,60,000 tons, of which 1 lakh will be for export and the remainder for internal consumption.

The emphasis on industrialisation has consequently enhanced the importance of mineral development and necessitated large scale increases in the output of iron ore, coal, manganese ore, limestone, dolomite, etc. On the basis of the capacity envisaged for different industries the targets of production to be achieved by the end of the Second Plan period, in respect of some of the important minerals used for iron and steel production, are 12·5 million tons of iron ore, 60 million tons of coal, 2 million tons of manganese ore and 23·3 million tons of limestone.

Although it may be true in a general way that indigenous mineral resources have been tapped to varying extents, little regard has been given to their conservation and maximum utilisation. Only those deposits which yield marketable grades of ore, are exploited at present, leaving the low grade deposits *in situ* or in the dumps. Fines produced during mining also invariably go to waste. It is estimated that for every ton of high grade ore raised, an equal amount goes to waste in the form of low grade ore and fines. For proper conservation of mineral wealth ore-bodies should be mined in full, followed by upgrading of the low grade portions of the deposits. This aspect has received due attention in the National Metallurgical Laboratory for the past eight years. Low grade samples of manganese, chrome, iron, lead-zinc and uranium ores, pyrite and sulphur, fluorspar, limestone, magnesite, gypsum, vermiculite, graphite, etc. from all over the country, have been investigated in the Laboratory and methods of concentrating them have been developed.

Processes developed for beneficiating some of the important raw materials like iron ore, manganese and chrome ores, fluorspar, etc., to the specifications for use in iron and steel production are outlined below :

Iron ore

India has very large reserves of high grade iron ore, the principal deposits being located in Keonjhar, Sundergarh and Mayurbhanj districts of Orissa ; Singhbhum in Bihar ; Dhalli-Rajhara, Bailadila, Rowghat and Jabalpur in Madhya Pradesh ; Dharwar, Bellary, Chitaldrug, Shimoga and Tumkur in Mysore ; Salem in Madras ; and Guntur and Nellore in Andhra Pradesh.

The necessity to beneficiate Indian iron ores does not arise in most cases. During mining operations, very appreciable quantities of fines are being produced which at present go to waste, but can profitably be used in blast furnace after sintering. It may be pointed out that for smooth blast furnace operation, iron ore should not contain more than 10 per cent of minus ½ inch fines.

A detailed study for the Bhilai Steel Plant has been made in the Laboratory on the sintering characteristics of iron ore fines from Rajharapahar deposits of Madhya Pradesh. The effects of variables such as coke and moisture contents in sinter mix, basicity and raw material proportions on the sintering time, and on the quality of sinter produced, have been studied. Optimum conditions for producing the best sinter have been determined. It was found that coke has a pronounced effect on sinter properties whereas moisture content directly affects

Mr. G. P. Mathur, B.Sc. (Met.)., Senior Scientific Officer, Ore Dressing Division, National Metallurgical Laboratory.

Mr. P. I. A. Narayanan, B.Sc.(Met.), M.A.I.M.E., Assistant Director, Ore Dressing Division, National Metallurgical Laboratory.

permeability and sintering rate. 6·1 per cent by weight of coke and 7 per cent of water were found to be the optimum for producing a good sinter. The basicity ratio for producing a self-fluxing sinter of good strength in the shortest time, was found to be 0·8. The amount of lateritic ore and return sinter fines in the charge, the method of preparing the sinter bed and variation in suction during ignition and sintering, also determine the sinter quality and the rate of sintering.

Low grade magnetite from Salem, Madras, was investigated for its amenability to beneficiation and subsequent sintering studies of the concentrate with a view to utilising these large deposits for starting an iron and steel industry in the South. The sample assaying Fe, 36·5; and SiO_2, 44·2 per cent was passed through wet magnetic separator after grinding to yield a concentrate assaying Fe, 64·3 and SiO_2, 9·6 per cent with a recovery of about 88 per cent Fe. Studies made on the sintering characteristics of the concentrate showed that optimum amounts of coke and water contents were 7 and 9 per cent respectively for producing a self-fluxing sinter with a basicity ratio of 0·85.

The Rajharapahar laminated iron ore, which will constitute a large bulk of the ore to be used for the Bhilai Steel Plant, is not of a high grade unlike most Indian iron ores. The ore assayed Fe, 54·8; SiO_2, 11·16; and Al_2O_3, 4·64 per cent and when washed after grinding to 2½ in. size followed by screening of fines, yielded a concentrate assaying Fe, 60·3 per cent with a recovery of nearly 84 per cent Fe. Tabling of fines and mixing the table concentrate with the washed ore improved the recovery to about 90 per cent for almost the same grade of concentrate.

Though a sample of iron ore from Bonai, Orissa, was of a fairly good grade, it was desired by the Union Ministry of Steel, Mines and Fuel to upgrade the ore to about 65 per cent Fe for export to Japan. Calcining the ore at temperatures ranging from 500°C to 700°C after crushing to 3″ size, eliminated most of the combined water, thereby upgrading it from 57·6 per cent Fe to over 64 per cent Fe.

Manganese ore

In steel making, manganese which is added in the form of ferromanganese, performs vital functions as a deoxidiser and desulphuriser. In addition, manganese in excess of that required to fulfil these functions, remains alloyed with steel contributing useful properties. For production of standard grade ferromanganese, the manganese ore should contain not less than 48 per cent Mn, the Mn/Fe ratio not less than 7 : 1, SiO_2 plus Al_2O_3 not more than 12 per cent and P less than 0·15 per cent.

The country's manganese ore reserves are estimated at over 112 million tons. The principal producing areas are Balaghat and Chindwara in Madhya Pradesh; Keonjhar, Koraput, Bonai and Bolangir in Orissa; Nagpur, Bhandara and Panch Mahals in Bombay; Sandur, Chitaldrug and North Kanara in Mysore; Srikakulam and Ganjam in Andhra Pradesh; Singhbhum in Bihar and Banswara in Rajasthan. It is reported that about 40 million tons of high grade ore have been exported during the past few decades. Almost an equal quantity is estimated to be available as low grade ore *in situ* and in the dumps accumulated during all these years in the various mining centres. It should be possible to recover most of the manganese from these as high grade concentrates by suitable beneficiation methods. As production of standard grade ferromanganese is difficult to maintain from hand-picked high grade ore alone from a mine, it is considered desirable to use a beneficiated product which will be of a consistent grade and of the required specifications.

The results of detailed investigation work done in the Laboratory on nearly 30 different samples collected from all over the country, have shown that concentration of manganese ores to make them suitable for ferromanganese production is not an easy problem as manganese ores are of different types requiring different treatments depending upon the gangue minerals present. The manganese ores of India could however be classified into four major groups from the point of view of mineral dressing depending upon the types of gangue associated with manganese minerals and their degree of association :

(*i*) Simple ores.
(*ii*) Ferruginous ores.
(*iii*) Garnetiferous ores.
(*iv*) Complex ores.

(*i*) *Simple ores* : These contain quartz, felspar, clay and micaceous minerals, amphiboles, pyroxenes, barytes, etc. as the common gangue. Such ores are easily amenable to beneficiation by simple processes like washing, heavy-media separation, jigging, tabling, magnetic separation and flotation. The choice of the process depends upon the nature of gangue minerals and the size at which they are liberated.

High grade concentrates could be obtained from low grade ores from Kachidana Mines and Netra Mines in Madhya Pradesh and Barajamda in Orissa, employing gravity and/or magnetic separation methods. The results obtained with a few important samples of this group are shown in Table I.

(*ii*) *Ferruginous ores* : These contain generally hematite and hydrated iron oxides as the major impurities. As the difference in specific gravities of manganese and gangue minerals is not appreciable, simple methods of beneficiation are not suitable for this type of ore. When conditions are favourable, hematite can be eliminated from manganese minerals by washing and high intensity magnetic separation. But in the case of most of the ferruginous ores, the above method, patented by the Council of Scientific and Industrial Research, is not suitable. A low temperature magnetising reduction roast process, which is applicable to all types of ferruginous ores, has been developed in the Laboratory. The process consists of converting the oxides of iron to magnetite and most of the manganese oxides

TABLE I

Simple manganese ores

Sample	Treatment	% Assay: Low grade ore Mn	Fe	Others	Concentrate Mn	Fe	Others	% Recovery Mn	Mn/Fe ratio in the concentrate
Kachidhana Mines, M.P.	Jigging at −4 mesh followed by tabling of jig tailing at 28 mesh	41·6	8·46	SiO_2 14·6	48·9	6·28	SiO_2 8·64	83·0	7·7
Barajamda, Orissa	Tabling at −10 mesh after classification ...	35·7	9·2	$SiO_2+Al_2O_3$ 29·9	47·7	6·07	$SiO_2+Al_2O_3$ 11·37	67·0	7·8
Kumsi, Mysore	(*a*) Tabling at 65 mesh followed by magnetic separation of table tailing	34·4	4·5	$SiO_2+Al_2O_3$ 33·3	46·1	—	$SiO_2+Al_2O_3$ 9·2	88·5	—
	(*b*) Cationic flotation of siliceous gangue ...	34·4	4·5	$SiO_2+Al_2O_3$ 33·3	47·0	6·0	$SiO_2+Al_2O_3$ 6·85	92.4	7·8

to manganous oxide by gaseous reduction in the temperature range of 400–600°C followed by magnetic separation after grinding to sustable size. The reduction reactions being exothermic in nature, the heat liberated can be utilised for preheating freshly charged ore to the reaction temperature in a suitably designed rotary, stationary vertical or multiple hearth furnace.

The manganese concentrate produced by this process becomes an ideal raw material and in some respects even superior to high grade run-of-mine ore, for production of ferromanganese. The strongly magnetic iron-rich portion carrying some manganese can be valuable as a source of manganese in pig iron.

Ferruginous sample from Chipurupalli, and Kodur in Andhra, Sandur and North Kanara in Mysore, Miragpur mines, Balaghat in Madhya Pradesh, Siljora-Kalimati, Joda and Sambalpur in Orissa, etc. were found amenable to the process and the results obtained with some of the typical samples are given in Table II.

(*iii*) *Garnetiferous ores*: These contain garnets as the major gangue, the elimination of which is not found possible by gravity or magnetic methods. Electrostatic separation is found to be effective for removal of garnets from manganese minerals. It has been found possible in some cases to float selectively the garnets from manganese minerals by employing cationic reagents. Since some garnets associated with manganese ores are themselves manganiferous viz. spessartite, etc. their separation results in low manganese recoveries in the concentrates, depending upon the amount of garnet eliminated. The results obtained with a typical garnetiferous manganese ore from Banswara, Rajasthan, are given in Table III.

(*iv*) *Complex ores*: Here the gangue consists of different types of minerals or is in intimate association with the ore minerals necessitating thereby a complicated beneficiation procedure, involving 2 or more processes indicated earlier. The concentrates obtained from such type of ores, sometimes fall short of the standard requirements in one of the constituents which however can be made up by blending with appropriate ores or constituents. The results obtained with complex ores from Tirodi, Miragpur and Jhabua in Madhya Pradesh, and Salur, Andhra are given in Table IV.

Chrome ore

Chromium is one of the important steel alloying elements because of its ability to impart additional strength, hardness and resistance to corrosion. Chromite is also used as a refractory in furnaces. For metallurgical purposes, chromite should normally contain at least 48 per cent Cr_2O_3 and a Cr/Fe ratio not less than 2·8 : 1.

The chief chromite producing areas are Cuttack and Keonjhar districts in Orissa; Hassan and Mysore districts in Mysore; Singhbhum in Bihar; and Krishna district in Andhra Pradesh. Other occurrences are known in Salem, Madras, Ratnagiri, Bombay and Chitaldrug, Mysore. A rough estimate places the country's proved reserves at about 1·3 million tons.

Detailed studies on a dozen different chromite samples, have shown that Indian chrome ores can also be classified into the following three categories depending upon the gangue minerals present and the beneficiation process required.

(*i*) Simple ores.

(*ii*) Ferruginous ores.

(*iii*) Chrome spinels.

(*i*) *Simple ores*: These contain serpentine, talc, chlorite, magnesite, calcite, etc., as the chief gangue minerals. These ores can be easily concentrated by gravity methods like jigging, tabling, humphrey's spiral, etc. or flotation and in certain cases by magnetic separation. However, in spite of obtaining high grade concentrates, the Cr/Fe ratio in most cases is found to be low due to iron being present in chemical combi-

TABLE II

Ferruginous manganese ores

Sample	Treatment	% Assay: Low grade ore Mn	Low grade ore Fn	Low grade ore Others	Concentrate Mn	Concentrate Fn	Concentrate Others	% Recovery Mn	Mn/Fn ratio in the concentrate
North Kanara, Mysore	Reduction roast of washed ore followed by wet magnetic separation at 35 mesh	33·30	19·60	$SiO_2+Al_2O_3$ 7·21	54·58	7·27	$SiO_2+Al_2O_3$ 9 66	77·0	7·4
Sandur, Mysore	Reduction roast of washed ore followed by magnetic separation at 200 mesh ...	30·18	21·9	—	52·6	7·15	—	55·0	7·3
Kodur, Andhra	Reduction roast of washed ore followed by wet magnetic separation at 35 mesh	33.49	13·92	—	52·87	5·68	—	66·6	9·2
Joda West mines, Orissa	Reduction roast followed by magnetic separation at 10 mesh	27·2	24·2	—	51·7	7·38	—	62·0	7·0
Koraput, Orissa	(*a*) High intensity magnetic separation of deslimed pre-heated sample at 10 mesh—Patented Process ...	38·9	10·7	—	47·6	6·0	—	74·8	7·9
	(*b*) Reduction roast followed by wet magnetic separation at 10 mesh ...	38·9	10·7	—	50·8	6·2	—	94·1	8·2

TABLE III

Garnetiferous manganese ores

Sample	Treatment	% Assay: Low grade ore Mn	Low grade ore Fe	Low grade ore Others	Concentrate Mn	Concentrate Fe	Concentrate Others	% Recovery Mn	Mn/Fe ratio in the concentrate
Banswara, Rajasthan	Electrostatic separation of 48 mesh deslimed ore ...	38·82	5·0	$SiO_2+Al_2O_3$ 28·28	47·10	4·51	$SiO_2+Al_2O_3$ 11·09	70·4	10·4

nation in the mineral chromite. The results obtained with some of the samples are given in Table V.

(*ii*) *Ferruginous chrome ores*: In these ores most of the iron is present in the form of its oxides as distinct from the rest in chemical combination in the chromite mineral. The method of upgrading such ores is same as the one outlined earlier in this paper for the treatment of ferruginous manganese ores, employing reduction roast and magnetic separation.

Of the various samples investigated only one falls in this category and the results obtained are given in Table VI.

(*iii*) *Chrome spinels*: These cannot be beneficiated by ore-dressing methods to any appreciable extent beyond the removal of free gangue minerals, as the chromite mineral itself is of a low grade due to the partial replacement of Cr_2O_3 by oxides of Fe, Al and ferrous iron by magnesium.

A sample from Dodkatur, Mysore, assaying Cr_2O_3, 26·29; FeO, 20·42; MgO, 19·23; Al_2O_3, 11·25 and SiO_2, 11·51 per cent contained serpentine, talc, bastite, calcite, tremolite and quartz as the principal gangue minerals. Even after beneficiation it could not be improved in grade to over 39·7 per cent Cr_2O_3. The large deposits of chrome ore occurring near Salem, Madras belong to this category.

Of the 12 chrome ores investigated in the Laboratory, ten fall under simple ores, and only one each under categories (*ii*) and (*iii*), indicating that Indian chrome ores in general can be easily beneficiated to high grades by gravity methods, but the iron in most cases is too high for metallurgical purposes. Some ores of Orissa, however, have a favourable Cr/Fe ratio and such ores should be carefully conserved for the metallurgical industry for production of standard ferro-chrome.

TABLE IV

Complex manganese ores

Sample	Treatment	% Assay Low grade ore Mn	Fe	Others	Concentrate Mn	Fe	Others	% Recovery Mn	Mn/Fe ratio in the concentrate
Tirodi mines, M.P.	High intensity dry magnetic separation of $-20+100$ mesh ore followed by wet magnetic separation of the highly magnetic fraction, at 100 mesh and electrostatic separation of feebly magnetic fraction ...	27·39	7·47	SiO_2 33·4 ; P 0·36	45·41	—	—	51·0	—
Miragpur mines, M.P.	Reduction roast followed by low and high intensities magnetic separations at 65 mesh and electrostatic separation of feebly magnetic fraction ...	34·45	8·19	$SiO_2+Al_2O_3$ 26·22 ; P 0·098	46·23	6·6	$SiO_2+Al_2O_3$ 19·42 ;	30·0	7·0
Jhabua, M.P.	Jigging of 4 mesh sample and tabling of jig tailing at 14 mesh followed by reduction roast of gravity concentrates and magnetic separation at 10 mesh ...	28·80	5·90	SiO_2 22·38	48·89	5·6	SiO_2 12·1	57·7	8·7
Salur, Andhra	Screening out of -35 mesh fraction containing most of the garnet from 4 mesh sample followed by reduction roast and magnetic separation at 35 mesh ...	28·63	12·68	$SiO_2+Al_2O_3$ 24·63 ; P 0·2	50·10	6·29	$SiO_4+Al_2O_3$ 14·3 ; P 0·21	47·7	7·9

TABLE V

Simple chrome ores

Sample	Treatment	% Assay Low grade ore Cr_2O_3	FeO	Others	Concentrate Cr_2O_3	FeO	Others	% Recovery Cr_2O_3	Cr/Fe ratio in the concentrate.
Kittaburu, Bihar.	Jigging of $-10+28$ mesh fraction followed by tabling of -28 mesh fraction. ...	34·97	17·75	SiO_2 14·9	51·23	22·5	SiO_2 3·44	82·8	2·0
Byrapur, Mysore.	High intensity magnetic separation of 65 mesh deslimed ore. ...	36·74	22·93	MgO 15·47	49·08	29·18		90·6	1·5
Nausahi, Orissa.	Flotation of the ground sample using sodium sulfonate at low pH ...	42·5	16·62	MgO 15·44	53·31	19·0		91·5	2·5
Boula mines, Orissa	Tabling of 35 mesh sample after classification. ...	44·7	17·18	MgO 15·23 ; SiO_2 13·48	53·11	19·89	MgO 13·27 SiO_2 3·5	94·4	2·3

Fluorspar

Fluorspar is used as a flux for metallurgical purposes, as a source of fluorine in the chemical industry and as a opacifier in the ceramic industry. With the present expansion of the steel industry, the requirements of fluorspar are expected to increase from the present 5/6 thousand tons per year to 15/20 thousand tons. The expansion of aluminium industry demands increased import of cryolite, which can be synthetically manufactured in India employing indigenous fluorspar, if sufficient reserves are available.

Workable deposits of fluorspar are known to occur only in the district of Drug and Jabalpur in Madhya Pradesh. It is now reliably learnt that extensive deposits of fluorspar have been discovered recently in Rajasthan.

For metallurgical uses, spar should normally contain 85 per cent CaF_2 with less than 7 per cent SiO_2 and 0·5 per cent Pb. Low grade samples from Madhya Pradesh and Rajasthan were investigated in the Laboratory and the results obtained are given in Table VII. Fluorspar was floated emyloying fatty acid, after xanthate flotation for removal of galena.

Wolfram

The principal demand for wolfram concentrates is for the manufacture of ferro-tungsten, special alloys, tungsten powder and tungsten carbide. The concentrate to be marketable should contain over 60 per cent WO_3 and Cu, Sn, As, S and P each less than 0·5 per cent.

Known workable deposits of wolfram occur in Rewat hills near Degana, Rajasthan, and the entire output recorded in recent years has been from this area. Some small deposits are also reported to occur in Bankura district of West Bengal.

A sample from Rajasthan assaying 0·11 per cent WO_3 was tabled at 35 mesh size followed by magnetic separation of the table concentrate to yield a wolfram concentrate assaying 66·3 per cent WO_3 with a recovery of 50 per cent WO_3 in the product.

Conclusion

As India possesses huge reserves of high grade iron ore, the question of large scale beneficiation may not arise for many years to come except in the case of

TABLE VI

Ferruginous Chrome ores

Sample	Treatment	% Assay						% Recovery Cr_2O_3	Or/Fe ratio in the concentrate
		Low grade ore			Concentrate				
		Cr_2O_3	FeO	Others	Cr_2O_3	FeO	Others		
Gunjang mines, Orissa.	Reduction roast followed by magnetic separation at 65 mesh	41·4	34·2	MgO 8·6 ; Al_2O_3 7·9	58·5	17·3	MgO 13·63 ; Al_2O_3 8·81	86·0	3·0

TABLE VII

Fluorspar

Sample	Treatment	% Assay						% Recovery CaF_2
		Low grade ore			Concentrate			
		CaF_2	SiO_2	Pb	CaF_2	SiO_2	Pb	
Drug, Madhya Pradesh	Xanthate flotation for removal of galena followed by fatty acid flotation of fluorspar ...	46·25	49·68	0·68	87·08		0·06	92·3
Ramorwali mines, Rajasthan	Xanthate flotation for removal of galena followed by fatty acid flotation of fluorspar ...	21·14	58·80	0·31	84·9		0·12	87·2
Bhagatwali mines, Rajasthan	Fatty acid flotation of fluorspar	56·48	34·70	0·29	89·84	7·4	0·12	91·2

low grade magnetite from Salem, Madras, and hematite ores of Dharwar and Ratnagiri areas of Bombay, and some of the deposits of Madhya Pradesh. The potentialities of the Salem deposits are high in view of the development in progress of the nearby Neyveli lignite deposits.

Due to the favourable position in which India is placed with respect to manganese in world trade, and because of the mineral conservation policy followed by the Government, beneficiation techniques are likely to be increasingly employed for manganese ores during the coming years.

Chrome ore producers, who at present are employing mostly hand-picking, are also expected to take to beneficiation techniques in the near future.

If the huge deposits of fluorspar recently discovered in Rajasthan are to be exploited, to make the country self-sufficient in this vital raw material, there is the necessity to put up a flotation plant for concentrating this mineral.

Increased use of high grade iron ore fines as well as beneficiated manganese and chrome ore fines, after suitable agglomeration processes, should see the establishment of more sintering and other types of agglomeration plants in the country.

DISCUSSIONS

Dr. Ratnam, Neyveli Lignite Corporation: Referring to the beneficiation of Salem magnetite ores, we have found in our small scale trials that 90 or 95% of magnetite could be separated from the ore, when it has been crushed to about 80 mesh size. We have now gained some experience in beneficiating this magnetite in a Dings Magnetic continuous wet separator. If the ore is crushed to about the same size of 60 or 80 mesh and passed through this magnetic separator 2 or 3 times, the same effect has been observed on a continuous basis. I just wanted to bring these details to the notice of the audience here and I am very happy of course that the N.M.L. are serious with the problem and trying to solve it for us.