Indian Manganese Ores and their Thermal Beneficiation for Ferromanganese

B. R. NIJHAWAN

A review is made of Indian manganese-ore resources and their characteristics discussed in the context of the question of their utilisation for ferromanganese manufacture with selected fuel, low in phosphorus, in an iron blast furnace or in a Soderberg electric furnace. The projected plans for ferromanganese production in the background of the steel expansions envisaged in the second Plan are outlined. Attempts made abroad in respect of pyro-metallurgical processes for thermal beneficiation of low-grade manganese ores are also discussed—and initial work done at National Metallurgical Laboratory in this field is noted and details of a pilot-plant scheme drawn up for thermal beneficiation of low-grade ores, including the design of the rotary furnace to be employed, are furnished. Mention is also made of the project on low-shaft-furnace smelting of iron ores with non-coking coals being set up at Jamshedpur through the joint efforts of National Metallurgical Laboratory and the Tata Iron and Steel Co. Ltd. Possibilities of conducting experimental smelting on Demag-Humboldt principle are also referred to.

THE slag dumps, tailing heaps and low grade discarded wastes of today are mines of tomorrow. As the ores get leaner, ingeneous new techniques are required for ore-dressing and extracting metallic values. The heavy drain on high-grade ores and the development of new techniques place high premiums on research in beneficiation and extraction metallurgy. These remarks hold good for Indian manganese ores in particular which represent one of India's biggest non-ferrous mineral assets both in respect of high-grade and low-grade manganese ores. This should not, however, encourage complacency—the low-grade manganese ores have also to be suitably upgraded in respect of metallic content and improvement in impurity contents chiefly of phosphorus by all scientific means and ingenuity at our command.

Excluding Russia, India probably ranks as the world's largest supplier of high-grade manganese ores. The incessant demand for manganese ores from overseas markets has largely been met by exports from India of raw unprocessed ores of high-grade. The sub-standard grades have hitherto been chiefly neglected or wholly discarded. The high-grade manganese ore is generally hand-picked from the manganese ore burden after blasting in opencast mining leaving the low-grade manganese ore with no prospects at present of economic utilisation. It is roughly computed that for every ton of high-grade manganese ore mined, there remains discarded at the mine site 1-2 tons of the low grade ore. It has been reported that one single large producer-exporter of manganese ore in Madhya Pradesh has accumulated over six million tons of such low-grade ores at the mine-face over the past decades lying as waste. Large dumps of low-grade manganese ores have likewise been accumulated in close proximity to other mines. This material which so far has been dumped aimlessly has got to be turned into a national asset by all possible scientific methods at our disposal. Whilst the estimate of high-grade manganese ores have been reckoned at about 60 million tons, the reserves of sub-standard grades are much greater. Deposits of high-grade manganese ores are not, however, inexhaustible. Over 40 million tons of the high-grade manganese ore have been exported to world markets during the past few decades. Whilst the indigenous manufacture of exportable grades of standard ferro-manganese in place of large shipments of the raw high-grade manganese ore has been recognized as of utmost national importance, mineral beneficiation and upgrading of low-grade manganese ores have not received due attention.

For most Indian manganese ores, upgrading flow-sheets have been drawn up based on our investigations and which are currently being made use of by those in the manganese mining and export trade. Manganese metal is a *must* anywhere in the steel industry. It needs emphasis that without manganese no iron and steel industry can really function. It may be interesting to note that if a third World War comes, the most important material on which the war efforts of a country would depend may well not be uranium or thorium or the

Dr. B. R. NIJHAWAN,
Director, National Metallurgical Laboratory.

hydrogen bomb but manganese because without manganese no steel can be made and without steel no war can be fought.

The stress in the second Five Year Plan laid on the mineral development has been fully recognized in the National Metallurgical Laboratory. And the scientific effort to develop flow sheets for upgrading low-grade Indian manganese ores forms an integral part of the broad-based industrial development of Indian ferrous and non-ferrous mineral and metal industries in which our Laboratory is today playing an effective role.

This Laboratory right from its inception initiated systematic survey of manganese ore resources on an all-India basis and undertook investigations on upgrading of low-grade manganese ores. Concurrently, researches have also been undertaken on thermal beneficiation of low-grade manganese ores by a two-stage process, and on electrolytic production of manganese and manganese dioxide. The results of a large number of investigation on low-grade manganese ores already completed in the National Metallurgical Laboratory show that concentration of manganese ores, to render them suitable for standard grades ferro-manganese production, is not an easy problem in view of the fact that different manganese ores require varied types of upgrading treatment depending upon the gangue minerals present. Indian manganese ores can be broadly classified under the following categories:—

1. Siliceous ores containing quartz and other light gangue minerals like apatite etc., as the principal gangue.
2. Ores containing ferruginous minerals as the principal gangue.
3. Ore containing appreciable amount of garnet.
4. Complex ores containing gangue minerals falling under two or more of the above categories.

These four types of ores have been comprehensively investigated. Low-grade manganese ores from Mansar Mines, Kachidhana Mines and Balaghat (M.P.), Kodur Mines (Andhra), Shivrajpur Syndicate (Bombay) and Barajamda (Orissa) fall into the first category and require gravity concentration methods such as heavy media separation, jigging, tabling or straight magnetic separation.

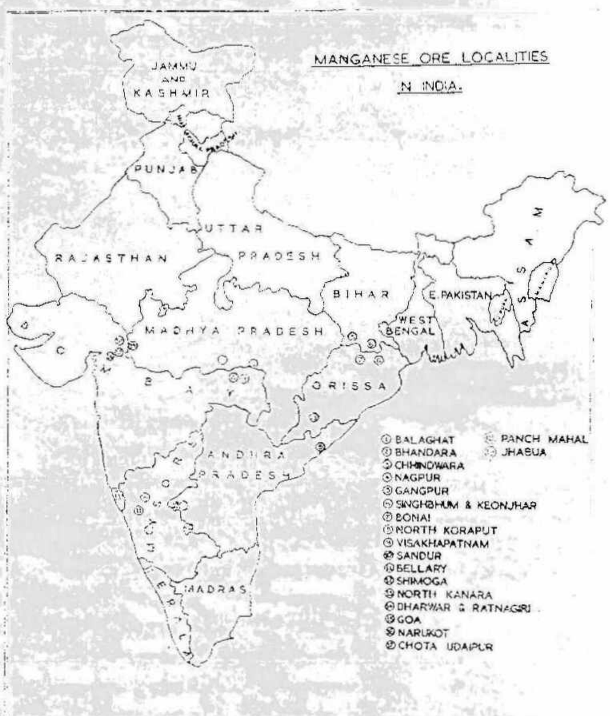
Ores of the second type can be effectively treated by a method developed at the National Metallurgical Laboratory and patented by the Council of Scientific and Industrial Research consisting of straight magnetic separation after desliming based on higher magnetic susceptibilities of haematite in relation to manganese minerals or by a process of magnetising reduction roast to convert the ferruginous minerals to magnetite followed by low intensity magnetic separation. This method is also applicable to ores containing non-magnetic gangue in addition to ferruginous minerals wherein low intensity magnetic separation following reduction roast treatment will eliminate the magnetite, high intensity magnetic separation will remove the feebly magnetic manganese constituents and the non-magnetic tailing will comprise siliceous and other non-magnetic gangue. Such treatments can be applied to the following Indian ferruginous manganese ores investigated at the National Metallurgical Laboratory :—

1. Nagri-Joida, North Kanara, Bombay.
2. Chipurupalli, Andhra.
3. Salur, Srikakulam district, Andhra.
4. Kodur Mines (Bed ore), Andhra.
5. Sandur, Mysore.
6. Miragpur Mines, Balaghat, M.P.
7. Kamji Mines, Banswara district, Rajasthan.
8. Sagur, Orissa.
9. Keonjhar, Orissa.

In category 3 fall manganese ores from Salur, Andhra, Banswara district, Rajasthan etc. Garnets possess almost the same specific gravity and magnetic susceptibility as manganese minerals and as such, gravity concentration and magnetic separation methods cannot effectively be applied thereto. Electrostatic separation has been found to be the most efficient for separation of garnet from manganese minerals though flotation in some cases has proved satisfactory.

Under category 4 fall complex ores that contain gangue minerals falling under two or more of the above categories requiring thereby three or even more steps for the elimination of the gangue and

FIG. 1



production of high-grade concentrates. In many cases of this type of ores, garnet, haematite, quartz, manganese silicates, felspar, apatite, hydrous iron oxides and clay are prominent gangue minerals present in intimate intergrowth with the ore minerals.

INDIAN MANGANESE ORES

The locations of manganese-ore deposits in India are shown in Figure 1 (page 141). The principal grades of Indian manganese ores, their grading and chemical analysis are given in Table 1. Country-wise exports of manganese ores from 1952-56 and output export and value of Indian Manganese ores are given in Table II.

Only a few of the Indian ores belonging to Madhya Pradesh, Orissa selected and first grade, and North Kanara selected grades are of the straight charging quality, i.e. ores not requiring any pre-treatment for the manufacture of ferro-manganese by the electric smelting furnace method.

The ratio of Mn. to Fe. in case of Orissa selected and North Kanara selected is high. These ores will have to be blended for suitable Mn/Fe ratio with lower grades to bring the manganese-iron ratio to about 7.

FERROMANGANESE MANUFACTURE

The necessity of manufacturing ferro-manganese in India instead of exporting raw unprocessed manganese ores, has been discussed from different platforms several times during the last two decades. But it is only now that concerted action is being taken to set up ferro-manganese plants in India utilising electric smelting of high-grade Indian manganese ores. Typical analyses of ferro alloys based on manganese are given in Table III.

Compositions of high carbon ferro-manganese

TABLE I

Region	Grade	Manganese as Mn %	Iron as Fe %	Silica as SiO_2 %	Phosphorus as P %	Ratio Mn/Fe
Madhya Pradesh	Dongri Buzurg	51 min	6.5 max.	5,0 max.	0.3 max.	
	First	48 min	7.5 max.	9.0 max.	0.15 max.	
	Second	45 to less than 48	9.0 max.	11 0 max.	0.15 to 0.30	
	Oriental mixture	49.25	7.50		0.150	6.5
Orissa & Singhbhum.	Selected	53.43	3.80		0.097	14.6
	First	48 min	4 to 8	3 to 8	0.15 to 0.20	
Typical Analysis :		48.64	7.38		0.12	6.6
	Second	45 to less than 48	8 to 12	5 to 8	0.15 to 0.20	
Typical Analysis :		42.67	11.19		0.081	3.8
	Third	38 to 40	11 to 19	5 to 13	0.15 to 0.20	
Typical Analysis :		42.67	11.19		0.081	3.8
	Fourth	30 to 35	19 to 25	—	—	
Typical Analysis :		42.67	11.19	—	—	
Koraput		45.00	10.00		—	4.5
Panchmahals Shivrajpur and Bamankua	Av. First.	47.10	5.00		0.26	9.42
	Medium	42.50	3.12		0.35	13.60
Banswara		44.17	3.18	18.26	0.055	12.0
Sandur Selected		35 to 42	16 max.	2 max.	0.02 to 0.05	
Typical Analysis :		42.00	14.00		0.03	3.00
Shimoga		37.50	11.5		0.025	3.26
North Kanara	Selected	53.51	5.36		0.0167	10.00
	Medium	42.50	10.00		0.04	4.25
Vizagapatam		39.49	8.36		0.139	5.00
Gujrat	First	48 min	5 max.	6 max.	0.24	
	Second	46 to less than 48	5 to 6	6 to 10	0.24 to 0.26	
	Third	Below 46	6 to 7	10 to 11	0.25 to 0.27	

TABLE II

(Quantity in '000 tons)

Countries	1952 (Tons)	Per cent	1953 (Tons)	Per cent	1954 (Tons)	Per cent	1955 (Tons)	Per cent	1956 (6 mths) (Tons)	Per cent.
U. K.	140	9.9	159	9.6	150	13.8	80	10.5	27	7.3
Sweden	10	0.7	10	0.6	4	0.4	1	0.2	1	0.1
Norway	18	1.3	4	0.3	6	0.5	13	1.7	4	1.1
West Germany	148	10.5	103	6.2	55	5.0	22	2.9	10	2.6
France	45	3.2	66	4.0	60	5.5	113	14.7	40	10.6
Italy	30	2.2	19	1.1	32	3.0	29	3.8	16	4.4
Japan	31	2.2	105	6.3	88	8.1	67	8.7	95	25.7
Canada	3	0.2	11	0.7	—	—	4	0.5	—	—
U. S. A.	931	66.0	1100	66.3	642	59.1	299	39.0	105	28.3
Others.	53	3.8	83	4.9	49	4.6	138	18.0	74	19.9
Total	1.409	100.0	1,660	100.0	1,086	100.0	766	100.0	372	100.0

Output export and value of Indian manganese ores are as follows :—

(Quantity in '000 tons)
(Value in Rs. lakhs)

Year	Manganese Ore Qty.	Value
	PRODUCTION	
1952	1,462	2,245
1953	1,902	2.948
1954	1,414	1,954
1955	1,570	2,188
	EXPORTS	
1952	1,409	2,155
1953	1,659	2,570
1954	1,086	1,520
1955	766	892

TABLE III

		Mn%	Fe%	C%	Si%	P%	S%
Standard ferro-manganese		78-82	12-16	6-8	1.0 max	.30-.35 max	.05 max
Low carbon ferro-manganese	1	90	-	.07 max	1.0 max	.06 max	.05 max
	2	80-85	-	.10 max	,,	.2 max	,,
	3	80-85	-	.20 max	,,	,,	,,
	4	,,	-	.30 max	1.0 max	.2 max	
	5	,,	-	.50 max	,,	,,	
	6	,,	-	.75 max	7.0 max	.25 max	
Medium carbon ferro-manganese		,,		1.50 max	1.50 max		
Spiegeleisen or	1	16-19	-	6.5 max	3.0 max		
Spiegel	2	19-21	-	,,	,,		
(alloy of iron & manganese)	3	26-28	-	,,	1.0 max		
Electrolytic manganese		99.98	.001 max	.004	nil		
Manganese metal Thermit		95-98	2-2.5	.06-.20	1-1.5		

made in India today in the conventional blast furnace and the quality used in America are shown in Table IV.

TABLE IV

	Indian Fe-Mn per cent	'Standard' Grade Fe-Mn per cent
Manganese	70/75	78/82
Carbon	6/8	7/5 max
Phosphorus	.5/.6	.35 max
Sulphur	.027	.05 max
Silicon	.55	1.24 max

The high phosphorus content in the Indian product is mainly due to the high phosphorus content derived from the ash in the Indian coke. Table V shows the difference in the quality of coke used in India in blast furnace production of ferro-manganese compared to that used by a ferro-manganese producer in America.

TABLE V—Coke Analysis

	India	America
Phosphorus	.18/ .25%	.01/.012%
Iron	1.25/2.3 %	.75/.85 %

The average Indian ore "oriental mixture" has the following approximate composition :—

Mn	Fe	SiO_2	Phosphorus
48/52%	6/8%	8%	0.10%

The manganese-iron ratio is about 7 : 1 against the Caucasian ore ratio of 60 : 1, Gold Coast 10 : 1 and Brazil 12 : 1.

This quality manganese ore together with the Indian coke currently used does not give a blast furnace smelted ferro-manganese of desired analysis for the export market. By careful selection of ore resources, it is possible to get manganese ore of lower phosphorus content from Madhya Pradesh, i.e. having about 0.09 phosphorus maximum. The most serious drawback however is the Indian coke, which has an average phosphorus content of 0.2% and an iron content of 1 to 2.5%. Over 2.25 tons of coke are required to produce a ton of ferro-manganese in an iron blast-furnace and the phosphorus introduced in the ferro-alloy derived from the coke alone would be about .4%. It may be pointed out that the iron content of the Indian coke, and the low manganese iron ratio in the Indian manganese ores dilute the ferro-manganese thus lowering the final manganese content in the ferro-alloy made. Approximately .4% (66%) out of the .5/.6% phosphorus contained in the Indian ferro is derived from the coke. The crux of the problem is, therefore, to find a metallurgical coke with a much lower phosphorus content for blast furnace production of ferro-manganese. Although India does not have coals with very low ash, the most suitable grade available are the Giridih and Laikdih coals which have phosphorus contents of about .01/.05% and could be utilised for making the right type of metallurgical coke for blast furnace ferro-alloy manufacture. In the 'blend' used by foreign manufacturers of ferro-manganese, the manganese-iron ratio is not less than 10 : 1. Where coke of low phosphorus content is available as in the U.K., the Indian manganese ore is used straight for the production of ferro-manganese without blending. In the U.S.A. high grade Indian manganese ore is blended because the American iron ore used for ferro-manganese manufacture is high in sulphur and phosphorus compared to iron ores employed for the purpose in Europe. The Japanese use an ore with 33% manganese and 0.05% phosphorous and smelt it in electric furnaces, producing a ferro-manganese of over 70% manganese and 0.14% phosphorus contents. About 3 tons of this ore are used per ton of ferro-manganese made by the Japanese.

Briefly, the factors that govern the making of standard grades of ferro-manganese acceptable for export are :—

Manganese-ore :

1. The manganese iron ratio should be as high as possible.
2. The phosphorus content should not exceed .1% to .13%.
3. The silica and alumina contents should not exceed 8 and 10% respectively.

Coke :

1. The fixed carbon content should be 77% minimum.
2. The iron and silica contents should be 1% and 10% maximum respectively.
3. The phosphorus content should be .065% maximum.

There are several ways in which the problem of making a ferro-manganese of the 'standard' grade could be tackled in India. Some of these are :—

1. The quality of the metallurgical coal could be improved by washing and/or by blending with other low phosphorus coals.
2. The use of selected Indian coal that contains low phosphorus.
3. Electric furnace smelting.

With the type of coke used regularly in the production of pig iron, it is not possible to manufacture a high-grade ferro-manganese in the blast furnace. Giridih coal has a low phosphorus percentage of .02% but it is not always used for metallurgical purposes. If the coke from this area is exclusively utilised for the production of ferro-manganese it will be possible to produce ferro-manganese of the required standard. By trying out various blends of Jamadoba coal and other grades such as Bararee, it may be possible to produce a coke with fixed carbon of 75%, iron .5%, silica about 10% and phosphorus .064%. The manganese ores from the Ukwa and

TABLE VI—ANALYSIS OF COAL AND COKE* OBTAINED FROM THE COAL.

Particulars of coal	Ash % Coa	Ash % Coke	Vol. matter % Coal	Vol. matter % Coke	SiO_2 % Coal	SiO_2 % Coke	Fe_2O_3 % Coal	Fe_2O_3 % Coke	Phosphorus % Coal	Phosphorus % Coke
Laikdih Seam (Raniganj)	15	20.5	29	1.0	7.8	10.7	0.9	1.23	0.04	0.055
Lower Karharbaree Seam (Giridih)	15	19.5	26	1.0	10.4	13.5	1.2	1.56	0.005	0.007
Dishergarh Seam (Raniganj)	15	22.4	35	1.0	9.3	14.0	0.75	1.12	0.10	0.15
Coke Breeze (Laikdih Coal)	-	20.5	—	1.0	...	10.7	—	1.23	--	0.055

* Per cent yield of coke is assumed to be (100% V. M)
All figures are approximate.

TABLE VII—ANALYSIS OF COAL BLEND AND RESULTING COKE*

Blend No.	Per cent of Constituents of Blends: Laikdih	Giridih	Dishergarh	Coke breeze (Laikdih)	Analysis of Coke-%: SiO_2 Coal blend	SiO_2 Coke	Fe_2O_3 Coal blend	Fe_2O_3 Coke	Phosphorus Coal blend	Phosphorus Coke
1	45	20	30	5	8.9	11.9	0.93	12.4	0.057	0.076
2	50	20	25	5	8.8	11.7	0.94	12.5	0.054	0.072
3	55	30	10	5	9.2	12.3	0.99	1.32	0.036	0.048
4	60	25	10	5	8.7	11.6	0.98	1.32	0.038	0.051
5	60	30	5	5	9.1	12.1	0.99	1.32	0.033	0.044
6	65	25	5	5	8.7	11.6	0.98	1.32	0.035	0.047
7	70	15	10	5	8.4	11.2	0.95	1.28	0.041	0.055
8	70	20	5	5	8.4	11.2	0.97	1.30	0.036	0.048
9	50	45	...	5	9.1	12.1	1.05	1.40	0.025	0.033
10	55	40	---	5	8.9	11.9	1.04	1.38	0.026	0.035
11	60	35	--	5	8.8	11.7	1.02	1.36	0.028	0.037
12	65	30	—	5	8.7	11.6	1.00	1.33	0.030	0.040
13	70	25	—	5	8.7	11.6	0.99	1.32	0.032	0.043
14	75	20	–	5	8.5	11.3	0.99	1.32	0.034	0.045
15	80	15	...	5	8.3	11.1	0.95	1.28	0.035	0.047

* The analysis of coke has been calculated from that of the coal blend assuming a yield of 75% of coke for all the blends.

Bhaweli mines in Madhya Pradesh contain about .08% phosphorus and these ores may be stocked separately and utilized for the high grade ferro manufacture. Sufficient technical data may now be available on the advantage to be derived from washing of coals. Regarding Assam coals, though low in phosphorus, high cost of transport would rule out their use. In this connection the following specific Indian coals and seams could be effectively used for blast furnace smelting of ferro-manganese. It has been reported that at times standard exportable grades of ferro-manganese low in phosphorus have been made in India in the conventional iron blast furnace by judicious selection of coal for coking used in smelting operations. As such, the problem is neither new nor insolvable. Optimum blends of suitable coals can be made for use as shown in Tables VI and VIII. The Fuel Research Institute of the Council of Scientific and Industrial Research has done useful work on coal blending and washing in general.

It is often asked as to why, if the Indian steel industry is in a position to make use of indigenous ferro-manganese containing .5/.6% phosphorus, the American and other Western steel producing countries do not wish to take this grade of ferro-manganese ? Ferro-manganese is added to the liquid steel after it has been 'refined' and is generally added in the ladle for purposes of de-oxidation and alloying. The foreign manufacturers of ferro-manganese have been able to produce a low phosphorus ferro-alloy by blending manganese ores from different parts of the world thus enabling them to get an alloy with as low a phosphorus content (0.3-.35% max) as possible. When they can obtain this product of better quality, naturally they could not accept a relatively inferior quality such as Indian ferro-manganese made in the blast furnace.

THERMAL BENEFICIATION OF LOW-GRADE ORES

Large amounts of manganese pass into slags from open hearth furnaces during the production of steel. The recovery of manganese from such slags as well as from low-grade ores by pyro-metallurgical methods has received considerable attention in the

TABLE VIII

S. No.	Name of the party	No. and date of licence.	Capacity sanction per annum. (Tons)	Location.
1.	M/s. Jeypore Mining Syndicate Ltd., Madras.	No. L/42/2/54 dt. 12th March, 1954.	12,000	Rayagada (Orissa)
2.	M/s. Mysore Iron & Steel Works, Bhadravati.	No. L/42/1/54 dt. 8th March, 1954.	1,800	Bhadravati (Mysore)
3.	M/s. Electro Metallurgical Works Ltd., Bombay.	No. L/42/5/55 dt. 7th January, 1955.	12,000	Dandeli, North Canara, Bombay.
4.	M/s. India Ferro Alloys, Samastipur.	No. L/42/3/54 dt. 15th October, 1954.	20,000	Gomburria, Dist. Singhbhum.
5.	M/s. Tata Iron & Steel Co. Ltd., Bombay.	No. L/42/6/55 dt. 18th April, 1955.	30,000	Joda (Orissa).
6.	M/s. Combata Industries Ltd., Bombay.	No. L/42/4/54 dt. 18th October, 1954.	30,000	Tumsar (M.P.)
7.	M/s. R. B. Seth Shree Ram Durga Prasad (Ferro-Alloy Corporation) Tumsar.	No. L/42/7/55 dt. 9th September, 1955.	30,000	Garividi, Andhra.
8.	M/s. Hari Ram Dina Nath, Bombay.	No. L/42/8/55 dt. 22nd November, 1955.	18,000	Kanhan (M.P.)
		B.F.	1,53,800	
9.	M/s. Rungta & Sons Ltd., Bombay.		18,000	In Bihar (adjacent to ore mines in Orissa & Bihar). Exact location not yet decided.
		Total	1,71,800	

U.S.A., Australia and in Germany. Early approaches were in the directions that low-grade ores should be smelted in a blast furnace under conditions which would reduce most of the iron but little of the manganese, thereby forming a high manganese slag which could be used for the manufacture of standard ferro-manganese. More promising developments have been based on a three stage process.

1. Smelting of the low-grade ore or steel slag in a blast furnace to produce a high phosphorus spiegeleisen.
2. Preferential oxidation of the spiegeleisen in a converter or open hearth furnace to produce a high manganese slag low in phosphorus and iron.
3. Production of standard ferro-manganese in a blast furnace from the slag derived from stage 2.

Licences have so far been granted to the firms detailed in Table VIII, for setting up ferro-manganese smelting plants in India during the second Five Year Plan.

In Australia, at the Broken-Hill Proprietary Company Limited, work has been underway on the recovery of manganese from open-hearth run off and final steel slags by means of pyro-metallurgical operations to yield a ferro-silicon manganese containing about 70% manganese. Typical analysis of open-hearth slag so treated is given in Table IX.

TABLE IX

FeO	...	24.12%
Fe_2O_3	...	4.23%
MnO	...	31.00%
P_2O_5	...	2.07%
SiO_2	...	21.00%
CaO	...	13. 1%
MgO	...	2. 2%
Al_2O_3	...	2.28%

Reduction of the slag is undertaken in a two-stage process.

1. Under acid conditions to produce a high-phosphorus iron leaving manganese as far as possible in the slag.
2. Using phosphorus free, manganese enriched slag from the 1st stage to produce a manganese rich alloy and a slag virtually free of phosphorus and metallic oxides.

During the first stage, reduction of oxides of iron and phosphorus is carried out under highly acidic conditions and at low temperatures. The acid charge performs two function viz., by forming more stable silicates of manganese it assists in the retention of manganese in the slag, thereby contributing to the expulsion of phosphorus through alloying with iron. The first stage metal is of the order of the iron 91%, manganese 0.4% and phosphorus 4%. In the second stage, takes place the reduction of manganese-rich slag at considerably higher temperatures and highly basic conditions. yielding a ferro-silico-manganese alloy of about 70% manganese, iron 16%, phosphorus 0.3%, silicon 11% and carbon 3.6%. This process in Australia has not yet been wholly standardized and vigorous pilot plant research is in progress utilizing mostly open-hearth run-off slags although suitable mixtures of run-off and final slags may also be utilized. The cost of producing manganese-iron alloy through this two stage process will naturally be higher than that involved in direct reduction of high-grade manganese ores in a single stage reduction, but it is by no means prohibitive. And in case of an emergency shutting off overseas supplies of the high-grade manganese ore the benefits to be derived from this process are self evident. Incidentally, the by-product iron from the first stage can be usefully employed for foundry purposes or for steel-making through basic bessemer or basic open hearth processes. The use of final slag obtained from the second stage for cement manufacture could also be a useful proposition.

Some experiments on the thermal beneficiation of low-grade manganese ores were conducted in the National Metallurgical Laboratory.[1] The object of this treatment lies in the treatment of low-grade manganese ores through suitable thermal technique aiming at the production of an enriched manganese slag and iron as a by-product in the first stage followed by smelting of the enriched manganese slag preferably in an electric furnace of Soderberg type. On commercial scale the possibility of a combination of acid Krupp-Renn rotary kiln during the first stage to produce an enriched manganese slag followed by the use of basic Stuzelberg rotary furnace to smelt the manganese-rich slag to yield a manganese rich ferro alloy in the second stage may be considered. Alternatively electric smelting of the enriched manganese slag to produce the ferro-alloy can also be considered. The method is based on studies of free-energy values of the oxides of manganese, iron and phosphorus and thermodynamic factors involved in their reduction under optimum conditions of temperature and basicity. This has to be achieved through a two-stage process: (i) the first stage to be worked under acid conditions and at low temperatures to produce a high-phosphorus iron leaving manganese as far as possible in the slag; (ii) the second stage using phosphorus free, manganese enriched slag from the first stage to produce a manganese rich iron alloy of very low phosphorus contents. The by-product of high phosphorus iron from the first stage would be a useful byproduct for use in foundry as such or subsequent steel-making. Further study of the above subject on a pilot plant scale is expected to prove to be of considerable national and economic significance, if systematically persevered with.

EQUIPMENT FOR PILOT PLANT

It is proposed to carry out the reduction of iron in a rotary furnace essentially of Stuzelberg type with some modifications. The rotary furnace can also be tilted so that the charging of the ore can be done through a hopper and also at the end of reduction the metal can be tapped out at the other end into the ladle (see Fig. 2). The essential equipment involved for the working of the rotary furnace would consist of the following main items and auxiliaries :—

1. Electric crane : for charging the ore, tilting the kiln and handling of the ladle, etc.
2. Charging bin and hopper.
3. Compressed air tank.
4. Ladles.
5. Electric motors for rotating the kiln.

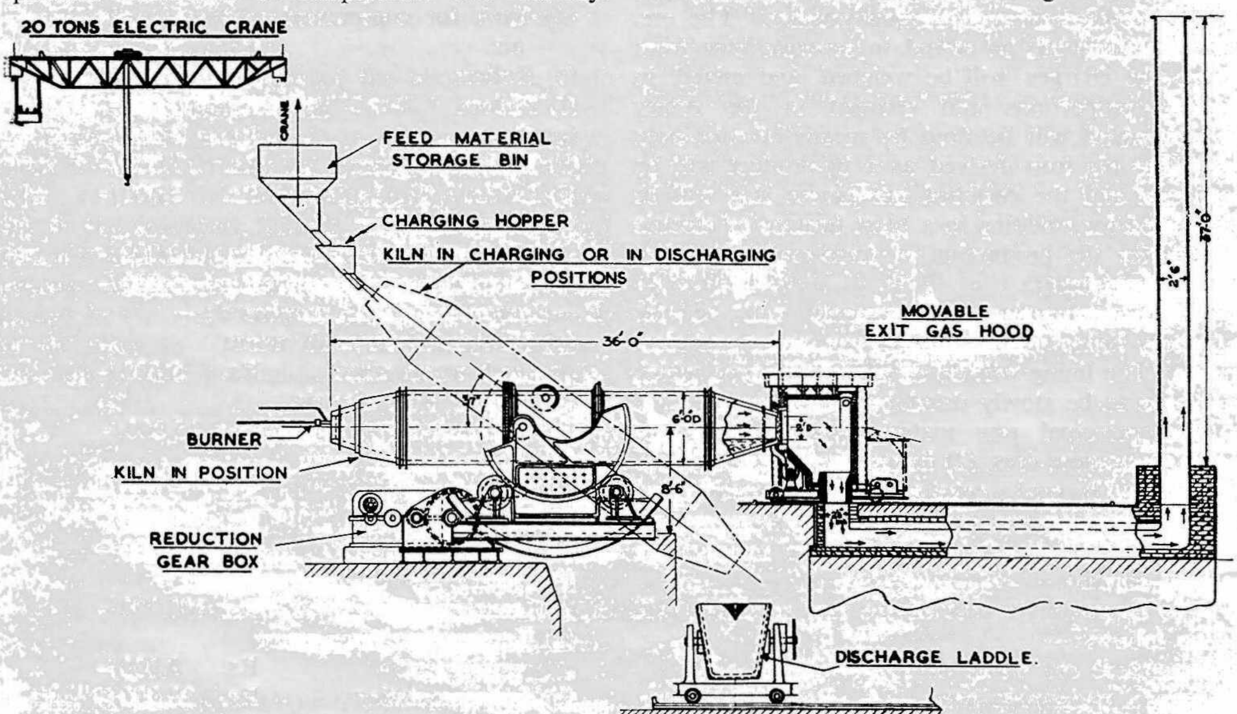


FIG. 2—*Rotating furnace.* (*Max. capacity : 15 tons*)

1. P. K. Gupte, G. P. Contractor and B. R. Nijhawan, Journal of Scientific and Industrial Research, 1953, Vol. 12A, No. 5, pp. 230-233.

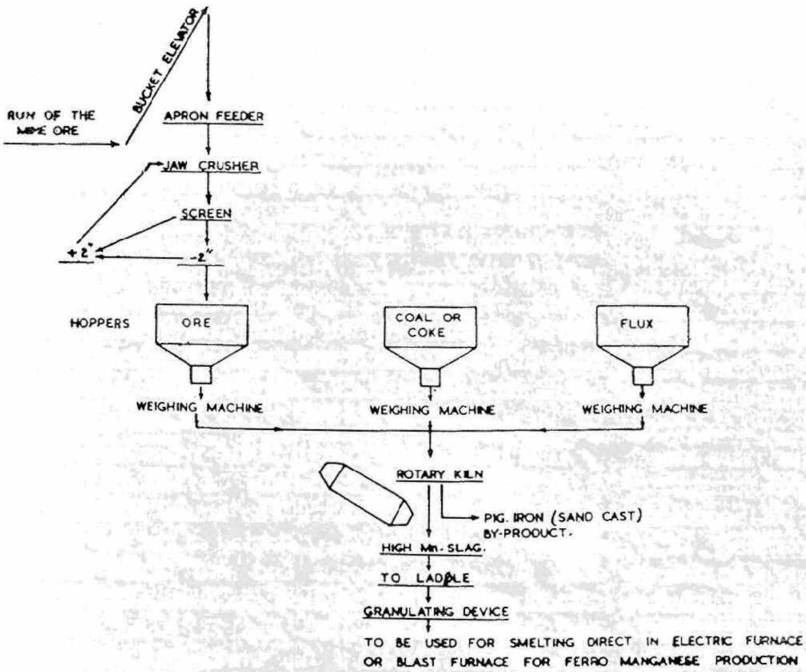


FIG. 3—*Flow sheet for thermal beneficiation of low-grade manganese ores.*

6. Reduction gear.
7. Mild steel chimney.
8. Blower for gas burner.
9. Trollies and rail truck.
10. Recuperator for heating the air.

The low-grade manganese ore will be elevated by means of a bucket elevator where it will be crushed and screened to $-2''$ size. The oversize will be recycled through the jaw crusher. The ore, coke and flux will be stored in separate bins from where the charges will be weighed and mixed in suitable proportions and charged in the rotary furnace which will be fired by means of coke-oven gas. The pig iron derived as a by-product will be sand cast and the enriched manganese slag will be granulated for smelting in a blast furnace or electric furnace for the production of ferro-manganese (see Fig. 3, flow-sheet).

The consumption requirements will be the refractory lining of the furnace, gas, water and electricity. The lining will be of monolithic type which will have to be slowly dried by gas burners.

The principal raw materials will be (1) low-grade manganese ores, (2) fluxes like limestone, bauxite etc. (3) coal, coke and coke breeze. Low-grade manganese ores can be obtained from manganese ore deposits in Orissa as they are mainly high in iron content.

The approximate cost of the raw materials will be as follows:—

Manganese ore waste or low-grade manganese ore	Rs.	45 per ton
Coal	Rs.	40 „ „
Coke breeze or coke waste	Rs.	20 „ „
Limestone	Rs.	25 „ „
Bauxite (flux)	Rs.	35 „ „

COST OF EQUIPMENT

A.—*Equipment to be fabricated*:—

(a) Rotary kiln shell	Rs.	80,000/-	approx.
(b) Steel chimney for the furnace	Rs.	5,000/-	„
(c) Hopper and storage bins	Rs.	15,000/-	„
(d) Tank for compressed air	Rs.	5,000/-	„
(e) Rollers	Rs.	6,000/-	„
(f) Pinions	Rs.	7,000/-	„
(g) Gears	Rs.	4,000/-	„
(h) Reduction gears	Rs.	7,000/-	„
(i) Ladles	Rs.	3,000/-	„
(j) Recuperator for preheating the air	Rs.	10,000/-	„
(k) Granulating device	Rs.	5,000/-	„

B.—*Equipment to be purchased*:—

(a) Electric motor with worm and worm wheel	Rs.	8,000/-	„
(b) Blower with electric motor	Rs.	15,000/-	„
(c) Electric motor with gear box	Rs.	9,000/-	„
(d) Pressure gauges	Rs.	2,000/-	„
(e) Gas burners	Rs.	3,000/-	„
(f) Electric crane—20 tons maximum load	Rs.	100,000/-	„
(g) Temperature measuring equipment	Rs.	8,000/-	„
(h) Instrumentation	Rs.	20,000/-	„
(i) Jaw crusher	Rs.	16,000/-	„
(j) Weighing machine	Rs.	15,000/-	„
(k) Conveyors—3 nos.	Rs.	24,000/-	„
(l) Screens	Rs.	6,000/-	„

C—

(a) Materials for refractory lining and pneumatic rammers	Rs.	20.000/- approx.
(b) Foundations for furnace etc.	Rs.	45.000/- ..
(c) Electrical wiring	Rs.	10.000/- ..
(d) Structural work	Rs.	57,000/- ..
(e) Piping etc.	Rs.	15.000/- ..
(f) Raw materials	Rs.	30.000/- ..
(g) Engineering charges and servicing	Rs.	27.000/- ..
(h) Contingencies	Rs.	15.000/- ..
Total cost (approx.) for items under A, B and C	Rs.	600.000

In the low-shaft furnace operating on Demag-Humboldt principle being set up under the Metals Committee by National Metallurgical Laboratory in collaboration with The Tata Iron & Steel Co. Limited, it is proposed to undertake trials into ferro-manganese smelting of Indian manganese ores.

It will also be not out of place to mention investigations initiated by Tata Iron & Steel Co. Limited, on the possibilities of making ferro-manganese in a German low-shaft furnace[2]. The process appeared to offer the following advantages :—

1. The use of low phosphorus non-coking coal, considerable reserves of which are available in India.
2. The possibility of using a wider range of manganese ores.
3. The manufacture of the alloy in separate self-contained units.

Experiments were made in Germany in a low-shaft furnace operating on the Humboldt principle, where raw materials were briquetted prior to charging in the low-shaft furnace. These trials showed that it was possible to produce an alloy low in phosphorus although excessive oxidation losses of manganese in the slags reduced the manganese content of the alloy to 60-70%. Further trials, however, have shown the possibilities of cutting down these oxidation losses in the slags through suitable additions.

The low-shaft furnace of Gute-Hottnungs-Hutte at Oberhausen (West Germany) has been successfully producing at the rate of about 48 tons per day of ferro-manganese.

Concerning the economics of ferro-manganese manufacture in India and reckoning on an approximate average export sale price of Rs. 140 per ton of the high-grade manganese ore, a million tons of which are currently exported from this country, the inflow of foreign exchange amounts thereby to about 14 crores a year. But if, after conversion of high-grade manganese ores into exportable grades of ferro-manganese (containing phosphorus below 0.3%) these million tons of high-grade manganese ores were to yield about 350,000 tons a year of ferro-manganese, it could fetch at the current price of the latter, about 28-29 crores of rupees a year. The economic benefits accruing thereby, are evident, apart from the fact that suitable methods for the utilisation of low-grade manganese ores, at present chiefly discarded, would also be evolved and be one of the greatest economic assets to the country. During the second Five Year Plan when the ingot steel production is to be stepped up to 6 million tons, the corresponding ferro-manganese requirements will rise to roughly 100,000 tons of ferro-manganese excluding railway and defence needs. It would be thus seen that at the scheduled production capacities of existing ferro-manganese licenses there will not be a great bulk of export. In my opinion the production of exportable grades of ferro-manganese in India should be stepped up to 250,000-350,000 tons a year. This will also in due course fully meet with the projected demands of the ferro to be met within the third Five Year Plan wherein the ingot steel production is stipulated at 15 million tons. This will leave surplus ferro-alloy for export to other countries particularly in South East Asia, Australia and Japan.

[2] Kutar, P. H., Eastern Metals Review, Vol. VI, No. 5, p. 320.

DISCUSSIONS

Mr. Krishnappa (*Mysore Iron and Steel Co.*): We have recently come across some deposits where the Mn:Fe ratio is 8:1 and 6:1 and the ores contain high silica, the manganese content varies from 35 to 45% and iron from 5 to 7%. I would like to know whether we can get ferromanganese by using these ores.

Dr. B. R. Nijhawan (*Author*): We shall gladly investigate the feasibility of utilising the manganese ores which Mr. Krishnappa has mentioned for ferro-manganese production. The ore's chemical composition appears to warrant these investigations to be tried on an experimental or pilot-plant scale.

Dr. V. G. Paranjpe (*Tata Iron and Steel Co. Ltd.*): The thermal beneficiation should be adopted for only such manganese ores which cannot be beneficiated in any other way, because it requires furnace capacity, consumption of fluxes and fuel, etc. The first operation of preferential reduction of iron can be done only on very acid slags. This means that heavy amounts of siliceous matter will have to be charged into the furnace. The slag has a drawback since it can never contain more than about 30-35% manganese. Now it appears that such a slag even though very rich in manganese in comparison with the iron content, would not be suitable for direct smelting to ferromanganese because the manganese content is very low. The remaining material is mostly acidic and will have to be neutralised by fluxes in the blast furnace which means huge quantities of basic fluxes would have to be added. Further the slag volume is likely to be high.

Dr. B. R. Nijhawan : I do appreciate Dr. Paranjpe's remarks. However, I would like to stress that thermal beneficiation method of low-grade manganese ores for ferromanganese production should be applied, as I emphasized in my paper, only for those ores which do not lend themselves to normal methods of ore dressing. We have found that the ferruginous manganese ores of our country especially that of Orissa, cannot be concentrated by the simple method of ore dressing, and therefore we have to find out means other than classical methods of mineral beneficiation for their upgrading. The low-grade ferruginous manganese are providentially low in phosphorus and also their phosphorus content gets equally partitioned between the enriched manganese slag and the metal iron and as such the phosphorus does not really present a serious problem.

Dr. Paranjape stated that the manganese in this enriched slag will at best contain 30 to 35% manganese. However, our experiments confirm similar data obtained in Australia that it is possible to obtain 54-55% manganese in the enriched slag. This slag lends itself to manganese ferro-alloy production just like high-grade manganese ores through subsequent reduction. The silica in the manganese enriched slag is not in any abnormal quantum compared to the high-grade manganese ore itself in which case also silica is present. It does not therefore necessitate the use of abnormal quantities of fluxes and lime. Even if 5-10% excess lime is to be used in this process than that used in conventional methods, this will certainly not warrant the outright rejection of the process.

If there are methods for upgrading ores other than ore dressing, certainly they must be explored. In this particular case a pilot-plant scheme to examine the process at a greater length has been drawn up and I hope that the results will be presented in due course. The findings will centainly be of great help to the ferromanganese industry now planning to tap the Orissa manganese-ore reserves.

Mr. S. K. Ghose (*Bird and Co. Privite Ltd.*, Calcutta) : I strongly support Dr. Nijhawan's remarks. I wrote a paper about two or three years ago in the *Eastern Metals Review* about manganese beneficiation. After that I received a letter from the General Manager of the Sandur Manganese and Mining Company seeking my advice about the disposal of 1,00,000 tons of manganese ore which contains about 28% manganese and about 24% iron with low silica. This particular type of manganese ore was not definitely amenable to any other treatment, i.e., washing, ore dressing or sorting and is being dumped in huge quantities. We must explore new methods for the utilisation of these waste products and I must heartily congratulate Dr. Nijhawan for his efforts in this direction.