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The Two-stage Production of High-carbon Ferromanganese in a Blast Furnace: A Method for the Treatment of a Lean Manganese Ore

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To meet the needs of the fast-developing steel industry of China, Jiangxi Xinyu Iron & Steel Complex has been using lean manganese ores, especially those with higher iron and phosphorus contents, to produce high-carbon ferromanganese (with manganese contents of more than 76 per cent and less than 0,25 per cent phosphorus) and other ferromanganese products by the two-stage blast-furnace process. The production practice has shown that the process is technically feasible and economically reasonable.

The key point of the process is to ensure that the manganese-enriched slag has good metallurgical properties. At present, the price of quality manganese ore is rising rapidly on the international market, and therefore the two-stage blast-furnace process is vital not only for China, but also for other areas where there are shortages of quality manganese-ore resources.

Introduction

China's steel industry has developed extremely rapidly. Steel output reached 65,8 Mt in 1990, up 77,9 per cent on the figure for 1980. This development has required ferroalloy production to increase at a similar rate or even faster in order to meet the anticipated demand.

China has abundant coal, but is short of electric power. Owing to this energy structure and, as the recovery of manganese in a blast furnace (BF) is higher than in an electric smelting furnace (ESF), China has adopted the BF process as its main method of producing high-carbon ferromanganese (HCFeMn). Jiangxi Xinyu Iron & Steel Complex not only produces steel products, but is also China's largest producer of ferromanganese.

It is known that the production of standard HCFeMn by the traditional BF or ESF process requires rich manganese ore, which has a high manganese-to-iron ratio and a low content of phosphorus. However, the distribution of quality manganese-ore resources is very uneven on the earth; most of these deposits are located in South Africa, Australia, Gabon, and Brazil. There are many manganese resources in China, most of which belong to the category of lean ore, and some of which have high iron and phosphorus contents. It is impossible to produce the standard HCFeMn from such ores by the traditional melting process. Now that China has become one of the world's major steel producers, the full utilization of domestic manganese-ore resources to produce quality ferromanganese has become an important task for Chinese ferroalloy producers.

China has been developing methods to treat lean manganese ore by the two-stage BF process since the 1950's. The work was pioneered by Shoudou Iron & Steel Company and some other steel enterprises, but the initial results were not satisfactory. In 1979, in cooperation with the Central Iron & Steel Research Institute of the Ministry of Metallurgical Industry and some other institutes, the Jiangxi Xinyu Iron & Steel Complex successfully implemented the two-stage BF process. From lean Mn ore, we have successfully produced an HCFeMn product containing more than 76 per cent manganese and less than 0,26 per cent phosphorus[1]. Since then, practice has shown that the two-stage BF process not only is suited to China's situation, but is technologically feasible and economically reasonable.

Principle and Process

In the first stage of the two-stage BF process, lean manganese ore is reduced selectively. The melting temperature of the BF and thermodynamic conditions are controlled in order to maximize the reduction of FeO and P_2O_5 by carbon, which minimizes the reduction of MnO. The manganese partitions into the slag phase in the form of manganese silicate, thus achieving the purpose of separating manganese from iron and phosphorus. The manganese content of the slag is about 40 per cent. This Mn-enriched slag constitutes a man-made high-quality manganese ore.

In the second stage, the Mn-enriched slag is smelted, together with a certain proportion of high-basicity and high-MgO sinter, to ferromanganese in another BF according to the production requirements. The flowsheet for the process is shown in Figure 1.

Production Conditions

The commercial production of FeMn by the two-stage BF process according to customers' needs began in 1979. The operations are stable and smooth. Typical production conditions are described in the following sections.

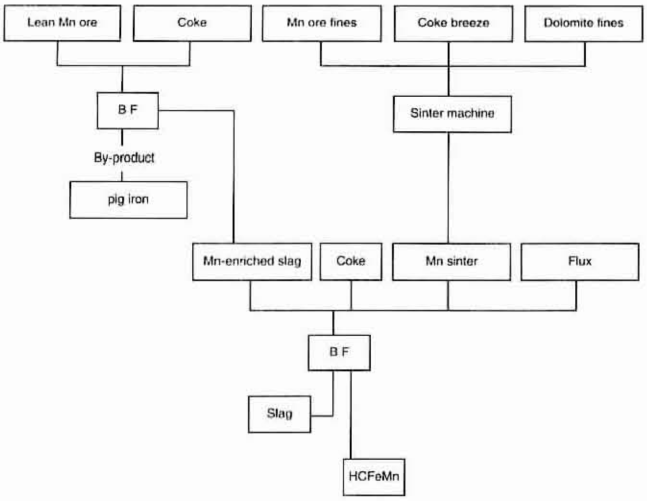

FIGURE 1. Flowsheet for the two-step BF technological process

Main Facilities

The BF for smelting Mn-enriched slag is a small one, with a hearth diameter of only 2 m. The temperature of the hot blast from the three Cowper stoves can be up to 1000 °C. In front of the BF, there is a slag caster. Before the molten slag is cast, the iron has already been well separated.

There are three BFs for ferromanganese smelting, each of which has three Cowper stoves and a hearth diameter of 4,2 m. The temperature of the hot blast can be up to 1050 to 1100 °C. A D700-31 blower is used. The molten metal is tapped into the ladle in front of the BF, and is stored after being cast on a special caster.

There are two 24 m^2 sinter strands specially used to produce high-basicity high-MgO sinters, which are sent direct to the bin of the BF.

Raw Materials and Fuel

The composition of typical raw materials is shown in Table I.

The coke used in the process is produced at our Complex. Its fixed-carbon and phosphorus contents are 85,43 and 0,0568 per cent respectively.

Production Data

The smelting data for the raw materials are given in Tables II and III.

Technical Analysis

There are three basic technical reasons for the success in ferromanganese production achieved by our Complex by the two-stage BF process.

Strict Raw-materials Management

Although the advantage of the two-stage BF process is that it can be adapted to treat lean manganese ore, the ore must be chosen carefully.

The quality requirements regarding fine ore that is to be sintered or manganese ore that is to be charged directly into the BF are the same as those for the conventional process.

TABLE II
SMELTING PARAMETERS FOR THE PRODUCTION OF Mn-ENRICHED SLAG

Slag composition, %		
	Mn	44,09
	P	0,016
	SiO_2	26,22
	Fe	0,60
Consumption of raw material and fuel, kg/t		
	Coke	488
	Mn ore	1 803
By-product iron, %		
	Mn	13,58
	P	1,02
Metal/slag ratio		437
Mn recovered in slag, %		86,87
Mean blast temperature, °C		931
Mean blast volume at normal temperature and pressure, m^3/min		107

TABLE I
COMPOSITION OF THE RAW MATERIALS

Material	Composition, %							Mn/Fe	P/Mn
	Mn	Fe	P	SiO_2	CaO	MgO	Loss on ignition		
Ores for Mn-enriched slag production									
Mn ore A	26,57	22,14	0,366	8,92			12,12	1,20	0,0138
Mn ore B	26,67	22,79	0,412	8,16			12,15	1,17	0,0154
Mn ore C	24,22	30,00	0,099	5,64				0,81	0,0041
Mn ore D	31,12	11,32	0,261	20,24			10,64	2,75	0,0084
Average	28,15	18,68	0,314	12,87				1,51	0,0012
Fines used in sinter									
Mn ore E	26,09	11,80	0,038	13,07				2,21	0,0015
Mn ore F	26,86	12,25	0,085	13,66				1,87	0,0042
Mn ore G	25,57	9,73	0,094	12,38				2,64	0,0037
Average	25,45	10,74	0,086	13,40				2,37	0,0034
Sinter	17,58	7,39	0,069	10,71	24,79	13,27		2,38	0,0039
Iron ore	1,96	64,89						0,03	0,0102
Lime lump				0,47	93,33	2,13			

TABLE III
SMELTING PARAMETERS FOR THE PRODUCTION OF FERROMANGANESE

FeMn composition, %		
	Mn	78,03
	P	0,220
	Si	1,29
Consumption of raw materials and fuel, kg/t		
	Coke	1 935
	Mn-enriched slag	1 896
	Mn sinter	1 014
	Iron ore	79
	Flux	924
Mean composition of ores in burden, %		
	Mn	33,38
	Fe	4,93
	P	0,037
	SiO_2	19,78
Slag composition, %		
	MnO	6,28
	CaO/SiO_2	1,48
Mn recovery, %		78,20
Mean blast temperature, °C		1 092
Mean blast volume at normal temperature and pressure, m^3/min		518

However, due to the large proportion of Mn-enriched slag used, we can widen the limitation of the Mn/Fe and P/Mn ratios so that more lean manganese-ore resources can be used.

The Mn-enriched slag in the BF process must have a lower SiO_2 content than that in the MnSi process. The ores used to produce Mn-enriched slag for the BF process can therefore have higher contents of iron and phosphorus, but the SiO_2 content must be as low as possible.

Our Complex chooses lean manganese ore according to these criteria. The individual ores are stored and processed separately, thus ensuring the fundamental conditions for smooth operation.

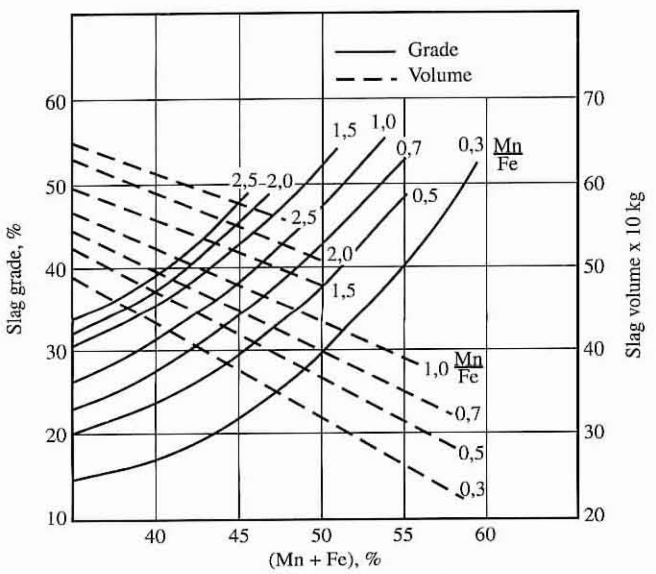

FIGURE 2. Effect of ore grade on the grade and volume of the slag

The two-stage BF process as outlined can be used for the production of HCFeMn, with a manganese content of more than 76 per cent and less than 0,25 per cent phosphorus, from the ores listed in Table I. The ores used to produce the Mn-enriched slag have a mean grade of 28,15 per cent manganese, a manganese-to-iron ratio of 1,51 and a phosphorus-to-manganese ratio of 0,0112. If the content of phosphorus in the product is no more than 0,33 per cent, the range of ores that can be used is wider.

The calculated relationships of the manganese and iron grades of the ores to the output and grade of the Mn-enriched slag are shown in Figure 2.

Improved Manganese Recovery and Coke Utilization

Ongoing efforts are being made to increase the recovery of manganese during the manufacture of ferromanganese. The lower the manganese content in the ores, the greater the slag volume, and the manganese in the slag must be reduced to a greater degree to keep the recovery high. Table III shows that the mean content of MnO in the slag is 6,28 per cent, and that the manganese recovery in the second step of the two-step BF process is 78,2 per cent. The MnO content of the slag from all three BFs was 4,93 per cent in 1990. The basic measures adopted were to increase the ratio of CaO to SiO_2 and the MgO content in the slag, and to keep the hearth temperature higher.

These measures are in conflict with the aim of reducing the coke consumption. Two main methods have been used to improve both the manganese recovery and the coke consumption. One of these is the use of high-basicity, high-MgO manganese sinter and lime lump instead of limestone, so that the flux is a clinker before it is charged to the furnace, and there is no decomposition of the limestone; the other method is to improve the profile of the BF by regulating the operation intensively, keeping the gas distribution reasonable, and increasing the utilization ratio of the heat and the chemical energy of the gas.

Metallurgical Properties of Manganese-enriched Slag

When the proportion of Mn-enriched slag in the burden is about 65 per cent, its quality has a significant effect on the melting result. In order to keep the operation running smoothly, the slag used in the BF process must possess good metallurgical properties besides a lower SiO_2 content.

The manganese-enriched slag produced by our Complex possesses not only a high manganese content, high manganese-to-iron ratio, low phosphorus content, good strength, stability during heating, and higher bulk density; but also a higher softening temperature and narrow softening-temperature range. When used in the BF, it can make the softening area lower and thinner, so that the permeability is improved, the temperature in the hearth increases, and the conditions for manganese reduction are greatly improved.

The softening data for our manganese-enriched slag and other comparable raw materials are shown in Figure 3 and Table IV. Samples 1 to 5 in Figure 3 correspond to samples 1 to 5 in Table IV.

Petrographic analyses carried out by Beijing Science and Technology University have shown that the main component in our manganese-enriched slag is tephroite ($2MnO.SiO_2$), generally in the form of long columns with a rhombic section. There is some galaxite ($MnO.Al_2O_3$) dis-

TABLE IV
COMPARISON OF SOFTENING PROPERTIES[2]

Sample	Composition, %						Softening temperature, °C						Softening range °C
	Mn	Fe	MgO	CaO	Al_2O_3	SiO_2	Start	4%	10%	20%	30%	40%	
1. X plant's Mn slag	33,95	10,48	0,52	2,74	11,67	33,62	615	665	702	914	1 081	1 083	481
2. Mn ore T	30,49	10,17	0,73	0,20	8,55	18,50	808	933	999	1 059	1 100	1 120	187
3. Mn ore L	31,30	3,67	0,43	0,50	5,04	32,10	883	966	1 012	1 043	1 072	1 089	123
4. Xinyu Mn slag	38,82	0,34	0,39	2,17	14,83	25,84	1 008	1 024	1 042	1 054	1 062	1 073	49
5. Xinyu Mn sinter	22,32	9,33	11,54	19,10	9,35	13,32	1 120	1 161	1 180	1 196	1 202	1 210	49

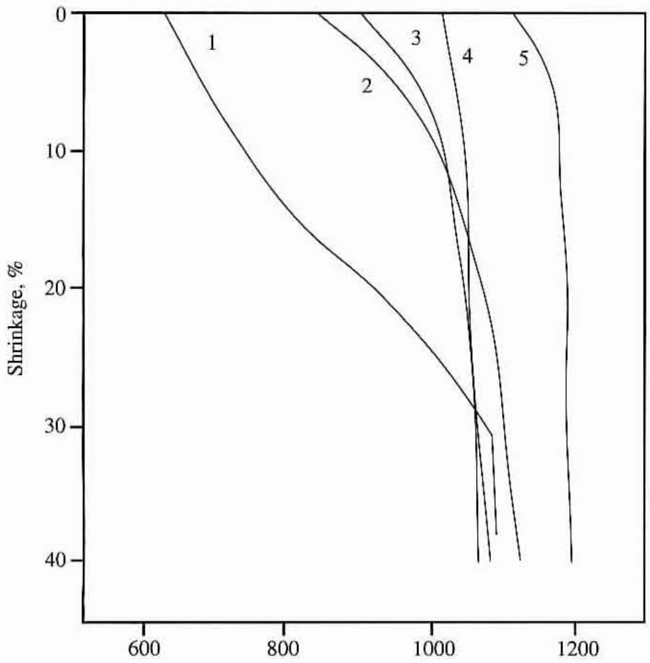

FIGURE 3. Softening–temperature curves for manganese-enriched slags and manganese ore

tributed in the tephroite, generally as the core of tephroite crystals. Minor rhodonite ($MnO.SiO_2$), melilite ($2CaO.Al_2O_3.SiO_2$–$2CaO.(Mn,Mg)O.SiO_2$), manganosite (MnO), and a glass phase are also present. The slag's high softening temperature and melting point are due to its content of components with high melting-points. The manganese-enriched slag produced by another plant (sample no. 1, Table IV and Figure 3) contains a very small amount of galaxite (melting point 1560 °C) but much more glass phase.

Future Improvements

The price of manganese ore has risen rapidly on the international market, from (CIF FO) $1,27 in 1987 to $3,8 DMT at present for 48 per cent manganese ore. The two-stage BF process is therefore a vital process. Its main advantages are as follows:

- a reduction in the cost of ferromanganese production and an increase in the profit of the enterprise
- promotion of the development of the domestic manganese-mining industry
- a saving in foreign currency.

In these respects the two-stage BF process is a success. However, some problems remain, the main one being the high coke consumption. The total coke consumption is about 2280 kg/t, excluding the coke consumed by the by-product pig iron. The total manganese recovery is about 68,72 per cent, which is not good enough. It is evident that the two-stage process must be improved further.

The following measures are planned to improve the process.

Improved Production of Manganese-enriched Slag

The technical operation will be improved to reduce the manganese content of the by-product iron to about 8 per cent and increase the recovery of manganese in the slag to more than 90 per cent.

The judicious use of ores, for example the simultaneous smelting of low-phosphorus ores, will enable a high-quality manganese-enriched slag and a high-value, high-manganese, low-phosphorus pig iron to be produced simultaneously. This will further improve the economic benefits of the first stage of the two-stage BF process.

Reduced MnO in the Slag of the Second Step

Practical experience has shown that the MnO content of the slag in ferromanganese making can be reduced to about 5 per cent, and the manganese recovery in the second stage can be as high as 80 per cent. The total manganese recovery in the process could therefore be as high as 75 per cent.

Reduced Consumption of Coke

To further improve the profile of the ferromanganese BF operation, the gas must be reasonably distributed and better utilized.

The use of an oxygen-enriched blast not only increases the melting strength, but also changes the temperature distribution inside the furnace effectively. This concentrates the heat in the lower part of the melting zone, and the temperature at the top of the furnace can be decreased. It is well known that the effects of oxygen-enrichment are enhanced when the coke rate is higher before the oxygen-enriched blast is blown in.

Reduced Phosphorus Content of Coke

It is noteworthy that more than 40 per cent of the phosphorus input to the BF in our Complex is from coke. The use of a low-phosphorus coal for coking will therefore have a significant effect on the product quality. Reducing the phosphorus content of the coke can reduce the proportion of manganese-enriched slag, or enlarge the range of lean manganese ores that can be used in ferromanganese making.

Conclusions

(1) The two-stage BF process is a method for the production of high-manganese low-phosphorus, quality ferromanganese from lean manganese ore. The basic requirements for smooth operation of the process are strict selection and management of the raw materials. The operating principles are to increase the manganese recovery and decrease the coke consumption at the same time, and to produce a manganese-enriched slag that possesses good metallurgical properties.

(2) The two-stage BF process is successful, but still needs further improvement. We expect that the use of oxygen-enriched blasting and other technically advanced measures will improve the melting parameters.

(3) The two-stage BF process is based on domestic ore resources and has been developed in response to conditions in China. Owing to the rapid rise in the price of manganese on the international market, this process is becoming vital, not only for China, but also for the areas that possess low-quality manganese resources but are rich in coal. Although the coke consumption of the process is high, the process is economically viable.

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