Technical Progress of Blast Furnace Ferromanganese Production in China

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ABSTRACT

The reason for the fast development of Blast Ferromanganese production in China has been annalysed in this paper. The author, based on his brief summarization for the technical progress of blast furnace FeMn process, has given forth some suggestions for the further improvement of the said industry after practically studying the situatiions faced by the BF FeMn producers.

1. THE REASON FOR THE FACT DEVELOPMENT OF FEMN PROCESS IN CHINA

China is a huge developing country. Her iron and steel industry has being developed rapidly. As known, iron and steel industry is a complex system with many aspects or branches, and ferroalloy is only one of them. The ferromanganese as an important kind of ferroalloy, is an indispensable material for steel making and there is a proverb in the industry as " no manganese, no steel". High carbon ferromanganese (HC FeMn) shares a large portion in manganese ferroalloys system. So, it is a strategic step to China steel development to adopt a good way for making HC FeMn, which should be suitable in China's conditions.

HC FeMn can be produced either by blast furnace or electric furnace process with carbon as the reducing agent. The BF process has been replaced abroad, but in China, it has became the main way for production of HC FeMn. The contrast between both processes is shown in Table 1, which was based on the long time production practice.

Table 1. The difference between BF and EF processes in China

Item	BF Process	EF Process
Mn recovery	80-85%	60-75%
Mn ore grade	Lean Mn ore with 28-30% Mn content can be used	Mn ore used should have Mn content over 35%
Energy type	Coke	Electricity
Product quality	Higher P content	Lower P content

In China, the BF process has remarkable superiorities over the EF one due to the features of Mn ore resources and energy available.

First, it is adaptation to the domestic lean Mn ore. China's Mn ore resources with reserve near 0. 6 billion MT, but only about 6% of it belongs to the rich grade, In order to meet the needs of increment of steel output and improving the FeMn-making indexes, China has to increase the amount of imported rich Mn ore in recent years. But the high price and the hard currency to pay bring unbearable burden to the most FeMn producers. This is why the BF process has been must in China.

Second, the restriction from the energy sources.

The development of China's electric power industry always falls behind the demand national economy in spite of its fast expanding. However, the coking coal is relatively abundant and cheap. it benefits BF process that use coke as its fuel.
During making China's Standard for ferromanganese, the concerned experts were linient in consideral of above mentioned sistuations and steel-making allowableness. In the standard for BF FeMn (GB4007-83), there are seven grades according to phosphorus content which can be up to 0.6% for different grade steel-making.

2. TECHNICAL PROGRESS OF FERROMANGANESE BLAST FURNACE

As above mentioned, development of China FeMn Blast Furnace is the must in such circumstances and promotion of technical progress appears very important whenlean Mn ore is used for the smelting. We have formed our own technical features and operation system.
The technical progress deals with many areas, following is a brief introduction.

2.1 Key step -gas cleaning

In 1950s, The problem of gas cleaning was not solved yet for FeMn Blast Furnace, and gas for its hot air stoves was supplied from pig iron Blast Furnace. Therefore, for ferromanganese making, the producer should haveseveral Blast Furnaces and should chose a small one or which was in the end of its service life, and made use of the gas from other pig iron Blast Furnace for stove heating for a short period production.
Xinyu Iron and Steel Corportation renovated the gas cleaning system of pig iron Blast Furnace in 1962 under the help of Maanshan Iron and Steel Design Institue, an overflow Venturi was adopted before the washing tower and a dedusting cyclone was added too. Since then, the barrier for FeMn Blast Furnace gas cleaning was overcome, and the FeMn Blast Furnace could be in production independently. There were several iron and steel producers who renovated old pig iron Blast Furnace into the ferromanganese one and new special BF ferromanganese factories founded in Hunan, Guangxi and Yunnan where Mn ore is abundant since they got the successful experience of Xingang Corporation. The ferromanganese output can meet the needs of steelmaking and the location of the producers is reasonable.

2.2 Raising the output and reducing the consumption of coke through flux sintering

High consumption of flux in ferromanganese smelting with lean Mn ore is a fatal weakness. During smelting, the carbon dioxide from the decomposition of lime stone is more harmful than the slag increment. See figure[2], which shows their influence. The reasons are:

1). Decomposition of carbonate causes heat consumption.
2). The carbon dioxide fron above mentioned will have the reaction, $CO_2 + C = 2CO - 165805KJ$, in the high temperature area. which not only consumes heat but also carbon.
3). affect smelting process, harmful for gas reasonable distribution and smooth operation.

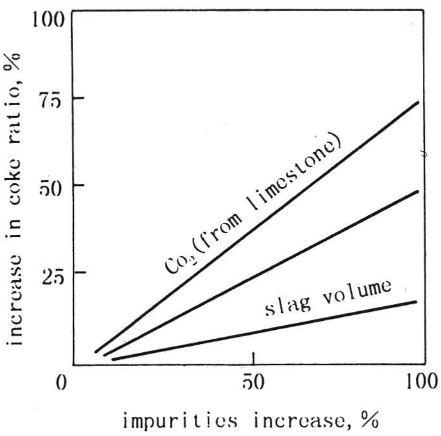

Fig. 1 The influence of burden impurities on coke ratio

The earlier solution for eliminating the harmful influence from the Boudouard reaction was using quick lime to replace the lime stone. Yangquan Iron and Steel Works started early to use quicklime and the effect was instant and remarkable when all limestone was replaced by the quicklime with coke rate reduced 21.7% and FeMn output increased 33.

9%. 40kg coke could be saved for each 100kg quicklime used, and the leaner the Mn ore, the better the effect[3].
Later on, Xinggang Corporation added all dolomite into the sinter mixture instead of directly into the" Blast" Furnace. The Mn sinter produced was of 1. 8 terinary basicity and 8% MgO content, and shaftkilns was built for lime stone calcining, all thesebrought good effect on BF FeMn smelting.
Now, to have the flux sintering by most producers are to charge high basicity, high MgO Mn sinter and quicklime to the furnace at the same tim. The mean Mn content of Mn ore charged to the furnace was 29.65%, SiO_2, 17.43% in 1960, the consumption of dolomite and lime stone for each ton of FeMn was 230kg only.
There are two points that should be kept in mind:
1). The lime stone can be overdone, but "half-cooked" should be avoided, and the fines should be screened off strictly.
2). The basicity of the sinter should be high and the performance good. Recent researches show once again that the Mn sinter with terinary basicity at about 1. 7 possesses the performance as high production rate, high cold mechanical strength, good efflorescence resistance , and good softening melting propertiers[4].

2. 3 Raise the recovery of Mn through reducing the MnO content in slag

The reasons of high Mn recovery of BF FeMn Process is:
1). the shaft is high, 70-90% of Mn contained flue dust produced at lower portion be retrieved by the burden and recirculated inside the furnace[5],
2). the influence from the gaseous circumstande, the thermodynamic calculation shows that, for the reaction MnO + C = Mn + CO (g), to decrease the CO partial pressure from 1 to 0. 3atm. is equivalent to the said reaction temperature being raised 50-70 degree centigrade, that also has been proved by the test result (see Fig. 2.)[6],
3). The other superiorities of BF can play big role in reducing the MnO content in slag.
There will be big amount of slag when smelting with lean Mn ore, and main Mn loss is in the slag. So for raising the Mn recovery, it is the key point to reduce the Mn content in slag. The relationship between the loss of Mn W(kg/t) in form of MnO in slag, slag volume G(kg/t), and MnO% in slag can be represented by the equation as follows:

$$W = 0.774(MnO)G \cdots\cdots (1)$$

The calculation results from equation (1) was shown in figure 3. From this figure, you can see that the slope of W-MnO line becomes low when slag volume be raised, i. e. MnO in slag will affect Mn recovery more seriously if the slag volume becomes large, so, more attention should be payed on reducing the MnO content in the slag. Xingang corporation has achieved the best results in our country which is shown in Table 2 [7]

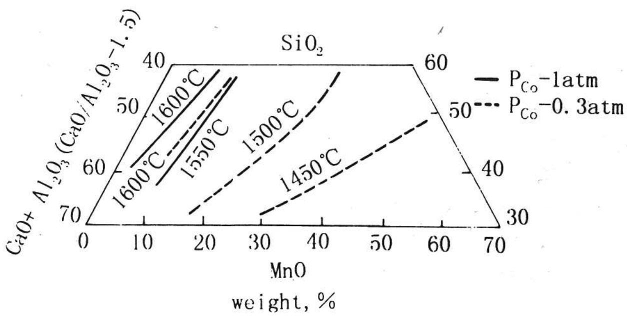

Fig. 2. Effect of CO partial pressure on the complete equilibrium composition of MnO-SiO_2-CaO-Al_2O_3 slags ($CaO/AL_2O_3 = 1.5$) in contact with Mn-Si-C sat. alloys

The concerned informations and researches have shown that the reduction of Mn oxide occurs at dropping zone, The chemical equation, reaction rate and integration can be expressed as follows:[8]

$$(MnO) + C = Mn(l) + CO(g) \quad (2)$$

$$d[\%Mn]/d\tau = KF\alpha_{MnO} \quad (3)$$

$$[\%Mn] = KF\alpha_{MnO}\tau \quad (4)$$

Here, K is the reaction rate constant that is the function of the temperature, activity $\alpha_{M}n$ depends on the composition of slag mainly, the reaction time τ depends on the height of dropping zone, and the reaction surface F is decided by the contact area of coke with the slag.

Table. 2 Production indexes and slag composition of Xingang Corp.

Items	1962-64	1965-74	1975-79	1980-91
Ore grade, Mn% $CaO+MgO$ deducted	32.44	32.40	29.85	32.93
Coke ratio, kg/t	2215	2040	1907	1722
Mn-recovery, %	69.46	77.52	79.43	84.24
[Si], %	1.10	1.01	1.07	0.99
Slag chemical composition				
CaO/SiO_2	1.26	1.33	1.42	1.49
MgO, %	3.57	6.03	5.53	8.97
Al_2O_3, %		15.10	14.00	11.75
2MnO, %	14.22	9.43	8.31	4.81

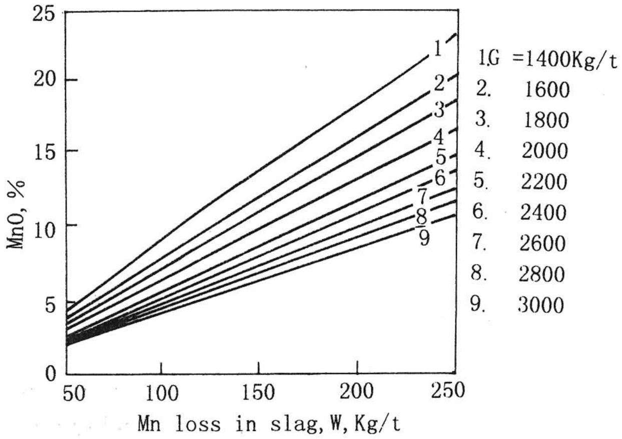

Fig3. Effect of MnO and slag volume on Mn loss

Based on the above analysis and production practice, the main ways for reducing MnO content of slag are as follows:

2.3.1 **Choose suitable slag formation system.**
It is appropriate to adopt merwinite $3CaO.2SiO_2$ as the main component of the slag, the parameters are: CaO/SiO_2 1.40-1.55, MgO 9-17%, [Si] 0.6-1.7% under conditions like that, the MnO content of the slag will be less than 5%. the Al_2O_3 level should be kept at 10-15%, if more, the high melting point mineral, spinel($MgO.Al_2O_3$) will formed too much to have a fluent slag, the conditions for Mn oxide reduction will be worsed, and it's also not good for the blast furnace operation.
There are some differences between different producer's conditions, the slag formation systems are also not the same, such as the Langfang Smeltery who use the water-quenched slag as filtering stuff for the sewage from the gas cleaning mand the main component of gehlenite $2CaO.Al_2O_3.SiO_2$ is desirable for the good perfomance. Some factores use lump lime as flux, adopt low MgO_2 slag operation, MnO in the slag is high.

2.3.2 **Adopt higher hearth temperature.**
Hearth is the place to end the smelting process, higher hearth temperature means higher temperture in the dropping zone, all of these can be judged by the[Si]%. Actually, since reaction of $Si+2MnO=SiO_2+2Mn$ exists in hearth, the level of (MnO) is a more sensitive parameter for theheath temperature. The main measures to raise the hearth temperature are:
1). adopt high basicity slag that has high melting temperature,
2). adopt super-fluxed, high MgO Mn sinter that has high mel&ting temperature and narrow softening temperature range,
3). increase the hot blast temperature and adopt oxygen-enriched blast to improve the temperature field inside the furnace so as to concentrate the heat in the dropping zone.

2.3.3 **The reasonable gas flow distribution**
A two peaks funnel-shaped CO_2 curve is reasonable for FeMn blast furnace operation. Such kind of curve means there is an inverted "V"-shaped softening-melting zone with the top at the higher position, i.e. dropping zone be enlarged, all of these benefit the reduction of MnO by elongating the reaction time and enlarging the reaction contact surface.
All above mentioed are the principles for each BF FeMn producer to reduce the MnO content in slag in China. The average level of MnO in slag was 8%, Mn recovery, 80.63% in 1996. For reducing the MnO obviously, the attention must be payed to:

200kg coke from the coke rate. They think that the two peaks funnel-shaped CO_2 curve obained or not may effect the coke rate 20-25%, output 25%-30%[3]. So, it should be regarded as the lifeline for FeMn BF.

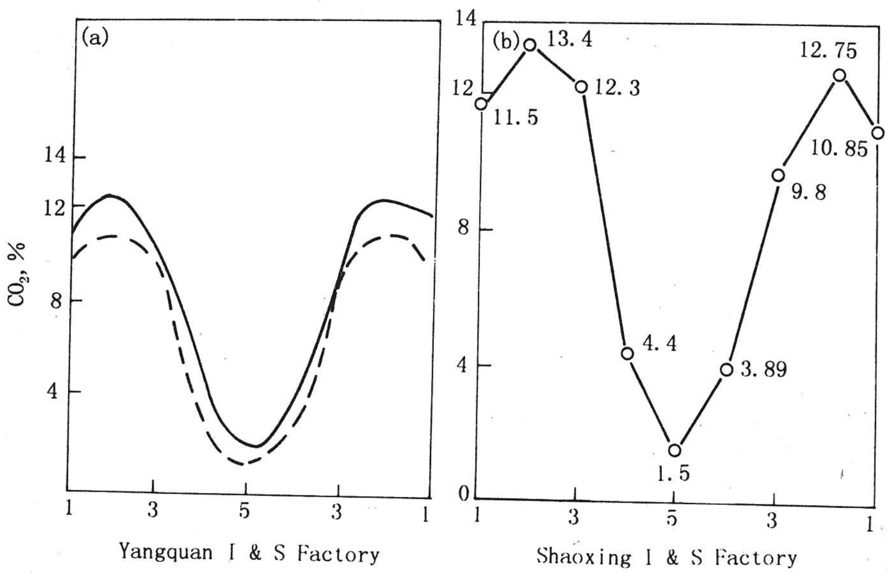

Fig 4 Two peaks funnel-shaped CO_2 curve

2. 5. 1 **In favor of the smooth operation and the reduction of MnO**

Since there is a main gas flow at the center, the adaptability to the outside changes has been enhanced and this is also in favor of BF smooth operation and heat and mass transfer inside the furnace. The burden preheat and redution in the preparation zone (shaft) is more vigorous, which make the work load lightened to the elaboration zone(bosh). That is the reason why the smelting intensity increases and coke rate decreases.

2. 5. 3 **Heat loss in radiation being reduced.**

There will be a heavy load and a weak gas flow at circumference by keeping a two peaks funnel shaped curve and the heat radiation from the shell thus be reduced. That is also in favor of the furnace without lining by forming a "burden lining" which move down slowly near the shell.

2. 6 **Progress on enviromental pollution control and comprehensive utilization**

Under the requirement for environmental protection, remarkable progress has being made in controlling the "three wastes" for FeMn BF after long time hard work in China. The gas cleaning water is filtered by quenched slag and so, the water for gas cleaning is circulated and reused; some producers use bag filters to collect the dust in gas. so, no water pollution at all, The surplus clean gas is used to heat boilers to generate the power or drive the steam turbine of blower directly; the water quenched slag is used for the production of cement, such as Wujin Alloy Works where a 1650KW power station and a 180,000 t/year cement plant was bulit around its 60 cubic meters FeMn BF and good economic result has being achived.

Some exploration for improving product quality and making more varieties has been made by Xinyu Iron and Steel Corporation. In 1979, Xingang Corporation was successful in producing qualified HCFeMn by two step method with lean Mn ore in BF, the research of MC FeMn making by blowing in the converter was also made in the same year. During the period of 1979-1985, the test of MnSi

1). the slag performance. High basicity is an important factor for the MnO reduction, but there is a limitation due to its high smelting temperature and unstable performace, which will leads to the operation difficult and increasing mechanical loss of Mn in slag. The formation of high melting temperature minerals, such as bicalcium silicate ($2CaO.SiO_2$) should be avoided so as to prevent the solid in suspension in the slag, meanwhile if slag basicity is too high, the effect of further decreasing MnO becomes megligible and slag volume increasing steeply will leads to economic loss,

2). the relationship between MnO in slag and volatilization loss of manganese, High temperature is the most important factor for Mn oxide reduction, but it is also the main cause led to the velatilization of Mn. The practice of Xingang Corporation shows that the volatilization is increased as the MnO content in slag being decreased (see table 3.). So, be careful to the loss through the volatilization while reducing the MnO content in slag and find out the optimum point between them. 3). keep reasonable gas flow model and operation smooth, once a furnace operation is in irregularity, there will be no way to the reduction of manganese loss.

Table 3. Mn distribution in the BF FeMn Process

Items	1978	1979	
		Sept.	Oct.
Commerial FeMn	77.04	79.58	82.18
Chemical loss in slag	17.98	14.06	10.81
Mechanical loss in slag	1.13	0.58	0.57
Dust loss	3.30	2.50	2.90
Volatilization loss	0.55	3.28	3.54
Total	100.00	100.00	100.00
MnO in slag	8.20	7.06	5.23

2.4 Improve BF structure and profile and prolong BF service life

The short service life of FeMn BF lining had been the most headache problem. There were no special regulations for the structure and profile of FeMn BF which was the same as pig iron BF. The lining would be seriouly eroded within six months after being put into opertion and came off within one or two years which will cause the abnormal burden distribution and difficult operation, Many attempts for improving the situation had been made in different factories and there were no obvious effect obtained. The service life of the lining, in general, was two to four years.

The final solution to this problem was found in Yangquan Iron and Steel Factory. Its BF No. 3 was changed from pig iron production to FeMn making in Dec. 1965. Two months later, the brick lining both at belly and lower middle shaft were eroded heavily and all were washed away after half year. The throat armour fell off too since the support loss from the below and the deformation due to high temp. and the bad circumstances. The gas periphery flow developed strongly which worsen the technical and economic indexes of production. In Oct. 1967, the dia. of big bell was enlarged for improving the gas distribution and a two peaks funnel-shaped CO_2 curve appeared, since then the furnace running became stable and smooth and the production parameters had been much improved. This was the 1st FeMn BF without lining.

Yangquan Iron and Steel Factory build a no-ling FeMn BF with water spray cooling to the whole body in 1971. Its service life have reached 15 years. Since this type of furnace has a long service life with much better production indexes, it had been adopted by every BF FeMn producer in China.

No-lining do not means no brick lining at all. The features of no lining BF is ; regular design for the hearth and bottom lining; the bosh, instead of lining, the cooling staves inlaid with fire brick are adopted generally; on the external of shaft and throat, water spraying are adopted for cooling; in the internal side of throat, the throat armour are replaced by thick steel plate which is welded onto the throat shell. The features are big throat, high bosh and short shaft. The Dia. of big bell, shaft angle being enlarged correspondingly after the Dia. of throat being enlarged.

2.5 Keep two peaks funnel-shaped gas distribution curve and smooth operation

In the 1960s, the two peaks pattern of CO_2 distribution was prevailing in China BF production. Yangquan Iron and Steel Factory, after long time experience with the no-lining FeMn BF production, first pointed out the superiorities of two peaks funnel-shaped CO_2 curve, that can reduce about making by oxygen -enriched blowing was made with 36 cubic meters BF.

3. DIRECTION FOR PERFECTING AND OPTINIZING THE BF FeMn PRODUCTION

China is the largest steel producter in the world with its output over 100 million Mt in 1996 which is still going up steadily. So, the market for FeMn has broad prospects. But the market now is in the process of deep going change and BF FeMn producer is facing serious challenges at every respect. The sucess or failure in meeting the challenge bears directly the result of rise or fall of an enterprise. Therefore, understanding the situation and taking right measures is the most important thing to the producers.

3.1 Promote combination of FeMn producers with Mn mine

Under the influence of comparative advantage principle, the ferroalloy production structure has been carried out a large scale of reformation with the location being transferred to the place where the raw material is produced. Combination or merging is also the tendency. In China, every FeMn producer should do the same according to the practical situations so as to increase their comprehensive competition in the home and abroad market.

3.2 Perfect raw materials preparation process

Based on the features of home Mn ore (lean, powdery, and miscellaneous), measures should be taken as follows:

3.2.1 The flux as lime stone and dolomite being charged in directly should be avoided so as to reduce the heat consumption.

3.2.2 Development the Mn ore sintering, that is not only the way for agglomeration, but also a measure for saving coke and increasing output.

3.2.3 Organise ore concentration and metallurgy allied researches for the lean and miscellaeous Mn ore, as for the coexisted ore of Mn, Fe, Pb, Zn, Ag etc. pyrometallurgy should be adopted for smelting the Mn-enriched slag and meanwhile recovering nonferrous or precious metals.

3.3 Expedite the technical reformation

The effective volume for each FeMn BF in China is not so large and the equipment used is not so good. but as long as the condition possible, each producer should learn the successful experiences at home and abroad, adopt new technology, expedite the reformation, increase the output to get the enterprise developed. At present, the most important task is to raise the blast temp, that is the most economic and effective way to reduce coke consumption and increase the output. There is abundant gas in FeMn BF production with a higher heat value It is a favorable condition for this purpose. High biast temp, oxygen-enriched blast plus pulverized coal injection is the direction for development of FeMn BF production.

3.4 Refine HC FeMn.

To refine the quality BF HC FeMn by converter blowing to get MC FeMn even L_C FeMn which will be of higher added value.

3.5 Perfect the facilities of emvironmenntal protection and intensify comprehensive utiliztion.

Change the wastes into valuable materials, go ahead to realize the modern civilized enterperise with no waste.

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