Technical Methods for Reducing Power Consumption in Smelting Extra-Low Carbon Ferrochromium

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ABSTRACT

Based on practical experiences, the effects of materials condition and process operation on power consumption in smelting extra-low carbon ferrochromium by electro-silicothermic process are given in this paper. Methods for reducing power consumption are also discussed.

1. Introduction

In industry, about 10% of chromium is used for casting, 15% for chemicals and 75% for FeCr while 80% of FeCr is used for the production of stainless steel and 20% for other alloy steels. In recent three decades, the rapid development of stainless steel both at home and abroad has given rise to acute competition in the FeCr market aiming at high quality and low cost.

Just as other industrial products, the competitveness of extra-low carbon FeCr is determined by price and quality. Under the premise of same quality, it will be determined by the price. Sometimes, affected by the relation between supply and demand, price will deviate from value. Disregarding this factor, price is determined by the production cost in general. Consequently, lowering production cost by selecting and monitoring raw materials and improving operating practice is the chief means to enhance competitiveness. Following reductants and chrome ores, power consumption ranks the third in the cost. To lower power consumption of smelting has always been a matter of great concern for the people involved in the metallurgy of ferrochrome.

Smelting extra-low carbon ferrochromium (hereafter abbreviated as ELC FeCr) by electro-silicothermic process in our plant has a history of more than 30 years. Based on the experiences of our plant, a presentation of the effects of raw materials and operating practice on power consumption and methods for its reduction will be made.

2. Effect of raw materials on power consumption

2.1 Effect of chrome ore on power consumption

Chromite, the principal raw material for the production of ELC FeCr, affects power consumption through its chemical composition and metallurgical performances. Chromite is the general name of minerals of chrome spinels. It belongs to an octahedral structure with structural formula $(Cr, Al, Fe)_{16} \cdot (Mg, Fe)_8O_{32}$. Its chemical formula can be written as $(Mg, Fe)O.(Cr, Al, Fe)_2O_3$, including 5 constituents of Cr_2O_3, Fe_2O_3, MgO, Al_2O_3, FeO with great variation in each constituent. The chemical composition of the chrome ores which have been used in our plant are listed in Table 1.

Table 1 Chemical composition of various chrome ore, %

Origin	Cr_2O_3	ΣFeO	MgO	Al_2O_3	SiO_2	CaO
Vietnam	46.87	21.58	6.71	9.64	4.06	0.40
Albania	48.80	14.31	18.29	8.40	7.17	1.90
Turkey	47.71	16.32	17.58	8.60	6.63	0.95
Iran	48.17	17.70	17.19	7.94	4.00	2.59
Philippine	49.22	18.41	14.55	13.18	2.78	0.92
India (ore fines)	51.84	17.53	12.03	11.40	2.46	0.92

The metallurgical performances of chromite is chiefly manifested in meltability and reducibility. Chrome ores from different origins may have similar chemical composition, but will have quite different metallurgical performances due to their different mineral phase structure. The main minerals affecting the metallurgical performances are spinels and silicates. The reducing temperature of chrome ore with close combination of Cr_2O_3 and FeO is lower than that of chrome ore with Cr_2O_3 and MgO. The content and combination mode of silicate in chrome ore will strongly affect the characteristics of ores. Chrome ore will become difficult to melt when silicate exists in the form of olivines in the ore and will be easy to melt when silicate exists in the form of serpentine and talc.

In the following, the effect of each constituent in chrome ore on power consumption will be discussed respectively.

2. 1. 1 **Cr_2O_3**

The Cr_2O_3 content of chrome ore is the main basis for evaluation of the ore. In the production of ELC FeCr by the piling up at bottom method, Cr brought into alloy from the ore constitutes about 65～70% of the Cr content of alloy. Consequently, the higher the Cr_2O_3 content in ore, the greater will be the amount of Cr obtained from the reduction of Cr_2O_3, resulting in high yield and low power consumption. If other constituents are not considered, increase of Cr_2O_3 in chrome ore by 1% will require the increment of about 8 kg of SiCr per ton of ore. The Cr brought into alloy from both SiCr and ore together increases by 8 kg. Deducting the power consumption for melting SiCr (0. 5 kWh is required for melting 1 kg of SiCr), power consumption will be reduced by 35 kWh for each metric ton of ELC FeCr.

2. 1. 2 **$Cr_2O_3/\Sigma FeO$**

FeO in ore which is reduced prior to Cr_2O_3 and almost completely enters into the alloy will directly affect the Cr content of the alloy; thus a certain ratio ($Cr_2O_3/\Sigma FeO$) in chrome ore is required.

Of course, if the FeO content in ore is too low, the ore will become difficult to melt and difficult to be reduced, thus affecting power consumption. Production of ELC FeCr generally requires that $Cr_2O_3/\Sigma FeO$ of the ore (whose relation with the composition of alloy is shown in Fig. 1) charged into furnace be more than 2. 8.

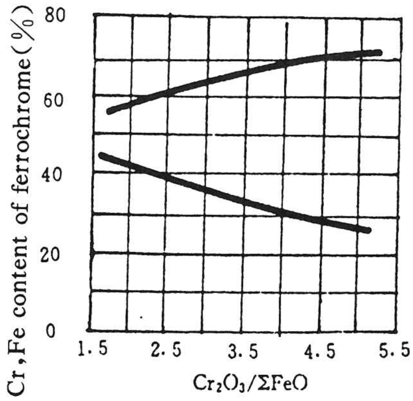

Fig. 1 Relationship between $Cr_2O_3/\Sigma FeO$ and composition of alloy

2. 1. 3 **Al_2O_3 and MgO**

MgO and Al_2O_3 in ore will all enter into slag, affecting the amount, composition and characteristics of slag during smelting. They will raise the melting point and viscosity of slag after entering into slag and affect the diffusion of Si and the reduction of Cr_2O_3, causing the increase of power consumption. The larger the value of $MgO/\Sigma FeO$, the more difficult it will be for the ore to melt. Therefore, the content of MgO and Al_2O_3 in ore is required to be low. In our plant, the ore for production of ELC FeCr is required to have MgO $\leqslant$ 16. 0%, $Al_2O_3 \leqslant$ 10. 0%.

2. 1. 4 **SiO_2**

All of SiO_2 in chrome ore enters into the slag, requiring CaO for combination. The higher the SiO_2, the larger will be the consumption of lime (1 kg of SiO_2 requires 2 kg of lime) and the larger will be the amount of slag, thereby increasing power consumption. Therefore, the SiO_2 content in ore should be as small as possible; it is required to be $\leqslant$ 6. 0%.

2.1.5 Behavior of various chrome ore during smelting

Various chrome ores used alone have been tested under the same condition of production. Different results have been obtained due to different metallurgical performances.

In the case of fusible ores, furnace charge melts rapidly and formation of alloy takes place at an early stage, resulting in fluid slag which erodes furnace wall readily. During the later stage of smelting, the temperature of the furnace goes down; desiliconsation becomes slow; crust forms on the surface of slag; resulting in difficult operation and poor separation of slag from alloy. Consequently, in spite of lower power consumption, great loss of metal in slag, low Cr recovery and shortened furnace life will result.

In the case of infusible ores, furnace charge melts slowly, formation of slag takes place at a later stage, basicity of first slag becomes high, resulting in hanging up of slag on furnace wall, shrinking of hearth, concentrated heating and easy erosion of furnace bottom.

It will be noted from Table 2 that differences among energy consumption when using a single kind of ore is not only caused by Cr_2O_3 content and $Cr_2O_3/\Sigma FeO$, but also (and more importantly) by the metallurgical performance of each ore. Based on the compositions and performances of several ores, arrangement of blending them for furnace charge has resulted in obvious improvement of smelting condition good shape of furnace lining, small fluctuation of furnace condition and lowered power consumption, and improvements in other indexes.

2.2 Effect of SiCr on power consumption

As a reductant in the production of ELC FeCr, the

Table 2 Power consumption in the case of use of single Cr ore and in the case of use of blended ores

Proportioning of ores		Power consumption (kWh)	Unit power consumption (kWh/t)
Single ore:	India	1400	1780
Single ore:	Philippine	1550	1910
Single ore:	Albania	1700	2150
Blended ore:	India:Albania=1:1	1530	1890
Blended ore:	India:Philippine=1:1	1390	1775
Blended ore:	India:Turkey=1:1	1360	1745

variation of the contents of the main constituents, Si and Cr (constituting about 75-80% of the alloy SiCr), not only closely relates with the production of SiCr itself, but also affects the unit power consumption for producing ELC FeCr.

According to the requirement of GB 5683-87, Si content in SiCr should be no less than 40%, and Cr content no less than 30%. SiCr produced in our plant generally contains Si 45% and Cr 33%, the fluctuation of Si content being larger than that of Cr content. Unit power consumption during normal operation amounts to 5250 kWh/t.

The smelting of SiCr by two step method is basically similar to the smelting of FeSi, most of power consumption being used for the reduction of Si; thus the unit power consumption directly relates with the Si content. Therefore, the increase of Cr content in SiCr within a certain range has no obvious effect on the unit power consumption, while there will be a decrease of unit power consumption by 85 kWh for decrease of Si content by 1%. On the premise of ensuring the requirement of the standard, production of SiCr with low Si and high Cr would be better. The amount of SiCr required for production of ELC FeCr varies with the Si content. With the lowering of Si and rising of Cr, the consumption of SiCr will increase and the power consumption for melting SiCr will also increase. Nevertheless, the output of ELC FeCr will increase as a result of the increase of Cr brought into alloy, as shown in the following calculation.

Under the condition of 1700 kg Indian ore and 1800 kg Turkish ore, power consumption of 5500 kWh for each heat of smelting ELC FeCr, SiCr with 45% Si and 33% Cr, ELC FeCr output 2.75 t, if Si content in SiCr lowers by 1% and Cr content raises by 1%, then consumption of SiCr will have to increase by 32.9 kg for each heat of ELC FeCr and power consumption for melting SiCr will increase by 14 kWh. However, ELC FeCr output will increase by 0.0487 metric tons due to the increase of Cr brought in by SiCr, thereby decreasing the power consumption. Making a balance of the increase and the decrease, the net result will be a lowering of unit power consumption by 30 kWh. Of course, that the use of SiCr with low Si and high Cr (every decrease of Si by 1% with corresponding increase of Cr by 1%) is preferred means the variation within the range of SiCr standard and does not mean any arbitrary variation.

Relationship between the use of SiCr with different composition and unit power consumption for smelting ELC FeCr is shown in Table 3.

Table 3 Relationship between SiCr composition and unit power consumption

Si content in SiCr (%)	46.35	46.13	45.07	44.03	42.85
Cr content in SiCr (%)	32.57	32.61	32.18	34.00	33.66
Power consumption (kWh/t)	1997	1972	1937	1922	1906

2.3 Effect of lime on power consumption

Lime, containing 90% CaO in general, is added as a flux in ELC FeCr production. Its function is to promote the dissolution of Cr spinel grains in order to raise Cr utilization and to lower the activity of SiO_2 to facilitate the progress of reduction reaction in order to raise Cr recovery.

2.3.1 Effect of CaO content

Pre-requisite to the improvement of Cr utilization is that all Cr ore grains should dissolve into the slag. In the production of ELC FeCr by piling up at bottom method, only when the ratio of CaO/Cr_2O_3 reached 2.0 can the ore grains be completely dissolved. According to the theory of reaction equilibrium, the condition for enhancing the reduction of Cr_2O_3 by Si is to lower the activityof SiO_2. With the addition of lime, CaO and SiO_2 will combine to form a stable silicate. Only when CaO/SiO_2 in slag reaches 1.8 can it be guaranteed that Cr recovery will be over 82%. Consequently, the higher the CaO content in lime, the lower will be the consumption of lime. Generally speaking, the total amount of slag will be reduced by 0.5% with increase of CaO content by 1%. The smaller the amount of slag, the lower will be the power consumption.

2.3.2 Effect of under-calcined lime

So-called under-calcined lime, namely, the lime which has not been calcined thoroughly, has a fair proportion of CaO still existing in the form of $CaCO_3$. After entering furnace, it will require additional energy for continued calcination. Therefore, the lime should be calcined thoroughly. Nor should it be over-calcined, since over-calcined lime has low activity and poor reactivity.

2.3.3 Effect of lime powder

Lime will become powder when moistened. In serious condition, its weight will increase by 30%. Formation of powder will lead not only to high consumption due to the moisture in lime, but also to inaccuracy of proportioning of furnace burdens, causing worsened furnace condition. In a later stage, large amount of lime to be replenished, black-colored slag and considerable loss of Cr in slag will result. A batch of normal burden for the 3000 kVA refining furnace in our plant consists of 3.5 tons of Cr ore (moisture about 7%). When using powdery lime, inclusion of slag still occurs even though the addition of lime has reached 3.7 tons. When using lumpy lime, 2.9~3.0 tons are adequate in general. Difference of unit energy consumption between them is around 150 kWh.

3. Effect of technological process and operating practice on power consumption

Since the four tiltable refining furnaces rating 3000 kVA have been put into operation, both technological process and operating practice have been undergoing constant improvement. In the beginning, the process of centralized addition of SiCr and striking arc by returned slag was used.

From mid-seventies onward, this process has been gradually replaced by the process of piling up of SiCr at the bottom which has the advantage of substantial lowering of power consumption and evident boosting of productivity. Both processes are shown in Fig. 2, Fig. 3 and Table 4.

The operating practice of starting up of smelting after drying up of furnace was completely eradicated. Direct charging and power supply delivered to the furnace with fresh lining were adopted.

With this practice alone, saving of energy consumption by 15000 kWh/(heat . cycle) has been attained.

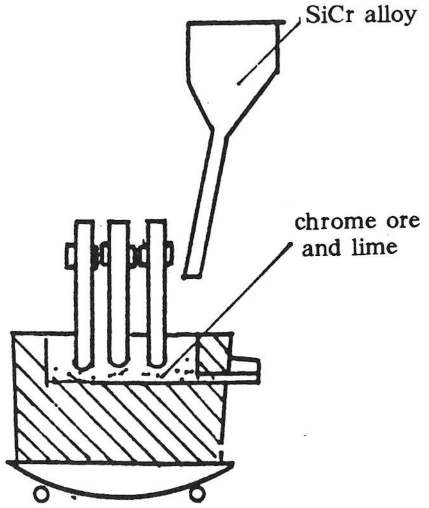

Fig 2. Process of centralized addition of SiCr

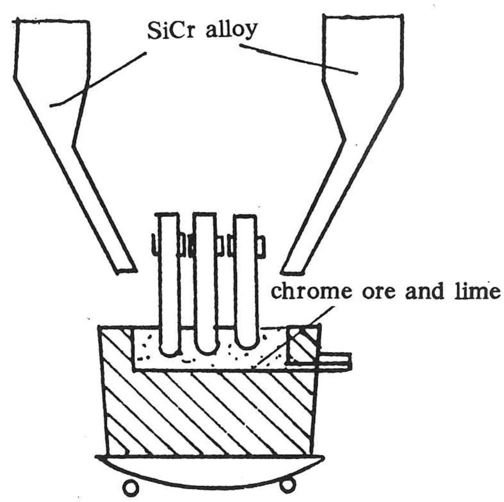

Fig 3. Process of piling up of SiCr at bottom

Through practice over 30 years, a series of successful experiences and mature practice (main points of which are listed as follows) have been accumulated.

3.1 The carbon content of alloy resulting from piling up process is higher than that resulting from centralized addition process. In order to lower alloy carburization and to stabilize arc and current, a small amount of fines of Cr ore concentrate is added onto the surface of SiCr.

3.2 After the striking of arc among the three phases of electrodes, add continuously and uniformly the mixture of Cr and lime, and keep arc uninterrupted.

Table 4 Comparison of operating practice of two processes

Procedure No.	Concentrated addition of SiCr	Piling up of SiCr at bottom
1	Tapping of previous heat finished	Tapping of previous heat finished
2	Return a small amount of slag of the previous heat to furnace	Add a small amount of Cr ore to furnace bottom and parts of furnace wall
3	Power on (V2=265V or 282V)	Add solid reductant SiCr
4	Add mixture of Cr ore and lime, melting period begins	Add a small amount of arc stabilizing agent onto the surface of SiCr
5	Change voltage (V=224V or 221.5V)	Power on (V2=282V)
6	Add solid SiCr after all burden have melted, refining begins	Add mixture of Cr ore and lime, melting period begins
7	Stir, sample, identify Si content of alloy and slag basicity and adjust them as required	Change voltage (V2=265V), refining begins
8	Tapping of alloy	Stir, sample, identify Si content of alloy and slag basicity
9		Tapping of alloy

3. 3 Handle the churning of slag and splashing of charge in time.
3. 4 Control Si content of alloy within 0. 5~1. 0% in order to guarantee the quality of product nd Cr recovery.
3. 5 Control the basicity of slag R=1. 75~1. 85.
3. 6 Use of different methods of piling up at bottom for the first heat of a new furnace will lower power consumption by 2000 kWh per heat.
3. 7 Control of power consumption per heat will effectively lower Cr_2O_3 in slag. Correspondingly, output per heat will increase and unit power consumption will be lowered.
3. 8 In practice, techniques in preparing burden, feeding of charge, casting, controlling slag basicity, monitoring slag color and alloy composition, probing furnace bottom and controlling the extent of reduction, etc. have been perfected.

4. Conclusion

Smelting of ELC FeCr by electro-silicothermic process has been carried out in our plant for more than thirty years. Through continuous improvement the power consumption for this process is lower than that for Perrin process and will continue to be competitive in the market of ELC FeCr with $C \leqslant 0.06\%$.