EFFECT OF CHROME ORE QUALITY ON FERROCHROME PRODUCTION EFFICIENCY

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ABSTRACT

Cost analysis of chrome ore reduction is one of the important issues facing ferrochrome producers in today's competitive environment. Much of this depends on quality and various ratios in the actual ore. The latter can have a direct bearing on electricity consumption and optimum efficiency of the furnaces.

While the industry has been successful in reducing costs by designing larger and more efficient furnaces, the role of the optimum blend of ore has perhaps been given less emphasis.

This paper will discuss the general specification and metallurgical characteristics of various chrome ores for producing high carbon ferrochromium on industrial scale. By analysing the results obtained from smelting, including chromium recovery and energy consumption, the determining parameters in total cost of ferrochromium i.e. chrome ore; reductant and energy consumption can be optimized.

Our study is based on actual experiences obtained from Faryab Ferroalloy Plant over a period of approximately three years.

1. INTRODUCTION

Faryab Mining Company (FMC) for many years has been the largest producer of chrome ore in Iran. The mining operation that commenced in 1963, is situated on the Aseminoon Mining Complex.
Up to 1995 the output was exported mainly to countries including Japan and China. Since then due to commissioning of its ferroalloy plant, besides the export of ore, high carbon ferrochromium has been produced.

The plant consists of two 12,500 kVA furnaces. The furnaces produce high carbon and extra high carbon ferrochromium, high carbon ferromanganese and silico-manganese. Both furnaces are equipped with bag filter de-dusting systems. Other necessary ancillary plants and equipment like raw material handling, batching, tapping, casting and product finishing exist.

During nine years of ferroalloy plant operation, experience and data have been gathered during high carbon ferrochromium production using this specific ore and various blended ores. For the present paper statistics of three consecutive years have been analysed and are discussed.

2. CHROME ORE SPECIFICATIONS

The ore is of podiform deposit that has been highly tectonized, thus the small grain size chromites have extensive microscopic intergranular cracks. The binder or veinstone is mainly serpentine with small quantity of magnesia ($MgCO_3$) in veins of chrome ore.

Melting temperature of the ore is 1650 – 1660°C [1].

We have used different ores with different blends. The main ore has been an ore with high MgO/Al_2O_3 ratio. Two other typical ores that are different in mineralogy and composition have been used and we have experience with regard to its smelting behaviour. In this paper we always refer to the main ore, and the results sometimes are comparable to these ores (Table 1).

SiO_2 and MgO contents of the ore have the same trend relative to the Cr_2O_3. Also for MgO it is in direct relation to SiO_2 in the serpentine (Figure 1).

A small amount of MgO exists in the form of magnesia ($MgCO_3$) in veins and cracks of the ore. This could be of significance in the reducibility of the ore. A lower MgO/Al_2O_3 ratio means a more dense chrome ore.

For the MgO/Al_2O_3 with the Cr_2O_3 in the ore the trend is opposite (Figure 2). Since the Al_2O_3 content of the ore has positive correlation with Cr_2O_3, the MgO/Al_2O_3 ratio increases with reduction in Cr_2O_3 content. Thus, as the Cr_2O_3 and Al_2O_3 decreases, the MgO increases.

Table 1. Chemical composition of chrome ore used.

Item	Main ore, mass%	Ore 2, mass%	Ore 3, mass%
Cr_2O_3	40 – 52	33 – 41	34 – 38
Cr/Fe Ratio	2.8 – 3.5	2.3 – 2.5	2.3 – 2.5
MgO	16 – 26	9 – 12	16 –18
Al_2O_3	6 –10	14 –18	22 – 33
SiO_2	6 – 10	5 –14	2 – 8
CaO	0.5 – 1	1.5 -3	0.5 – 1
S	Max 0.004		
P	Max 0.003		

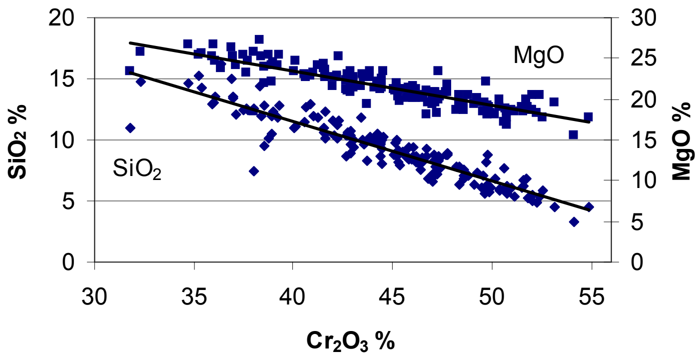

Figure 1. Ore $\%SiO_2$ and $\%MgO$ trends with $\%Cr_2O_3$

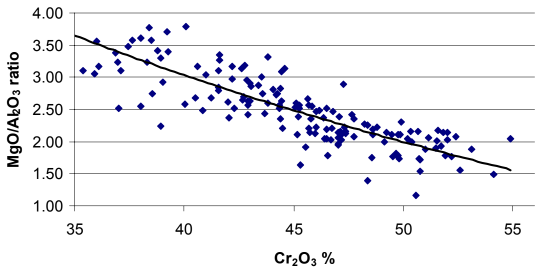

Figure 2. Ore MgO/Al_2O_3 ratio vs. $\%Cr_2O_3$

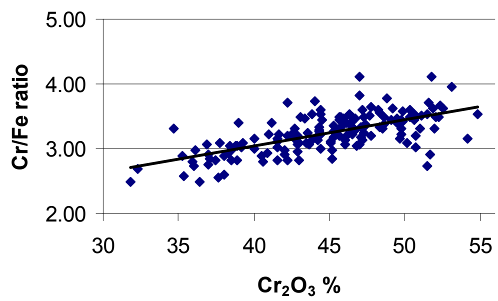

Figure 3. Ore Cr/Fe ratio vs. $\%Cr_2O_3$

The relation of Cr_2O_3 and Fe in the ore is in positive correlation. In general, as Cr_2O_3 increases the Cr/Fe ratio increases. This increase is relatively moderate (Figure 3).

3. METALLURGICAL BEHAVIOR OF CHROME ORE

3.1 Reducibility

Reducibility of ore, as has been indicated before [1, 2], is determined by its mineralogy (MgO/Al_2O_3 ratio), the MgO structural form in the chrome ore, chromite grain size, the extent of grains distribution in ore and the ore melting temperature.

Xiao and Hollapa indicated that solid-state reduction of chrome ore is of significance and this is a reaction between gas and porous solid [4].

The main mineral for this chrome ore is picrochromite with a high MgO/Al_2O_3 ratio that its significant for reducibility as explained in literature [1, 2, and 3]. Serpentine as the main binder is not like olivine very dense and hard, but has got enough porosity to allow a good contact between reducing gas and chromite grains. Also it has sufficient mechanical strength to withstand abrasion and crushing to reach to the furnace reduction zone.

The intensive chromite intergranular micro cracks will give a good surface area for reactions, helped by the small grain size of chromite that are distributed in serpentine. Other than spinels and serpentine, MgO exists as magnesia ($MgCO_3$) during heating and calcination stages in the furnace. The magnesia is possibly dissociated to MgO and CO_2 that creates some more surface area for reduction.

A high melting temperature of ore, if good reducibility in solid state exists, allows more time for the ore to be reduced before reaching the melting zone. This means less Cr_2O_3 losses to the slag.

3.2 Chromium recovery

Chromium recovery mainly depends on reducibility of the ore. From the input Cr to the furnace, other than recovered Cr to metal, the balance mainly reports to slag and some to furnace dust. With reference to hard and dense ore, the dust portion is low, but depending on ore reducibility and its size, the Cr_2O_3 content of slag could increase.

Since reduction of chrome ore in solid state is significant, fine ores could be used in the furnace. The fine chrome ore is very readily reduced in solid state before it is melted, resulting in a Cr_2O_3 content in the slag of 1.5 – 4.0 percent.

Also of significance is the complete separation of metal and slag during tapping and casting due to the low viscosity of the slag [1, 5], thus the losses from this part of the operation is very low.

3.3 Energy consumption

A good reducibility and especially solid state reduction could help utilising more CO gas for reduction of chrome ore.

As illustrated by Figure 4[1], there exists a range of MgO/Al_2O_3 ratio in slag where its melting point is the lowest corresponding to a minimum of energy consumption for the portion of slag to be melted. This corresponds to a MgO/Al_2O_3 equal to 2.1, but due to the presence of some Cr_2O_3 in the slag and other oxides, this figure is typically in the order of 2.2.

As result of the low reduction of Si to metal that is an energy consuming element when it is reduced with no economic benefit (85 kWh for 1% per MT FeCr [2]), there is some saving (Table 2).

Energy consumption for the period discussed is 56 kWh per 1% of Cr content of one metric ton of molten alloy.

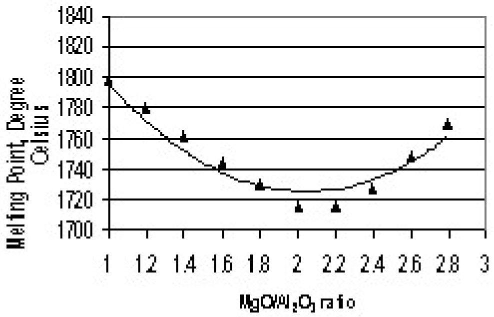

Figure 4. Slag melting points vs. MgO/Al_2O_3 (SiO_2 =32%)

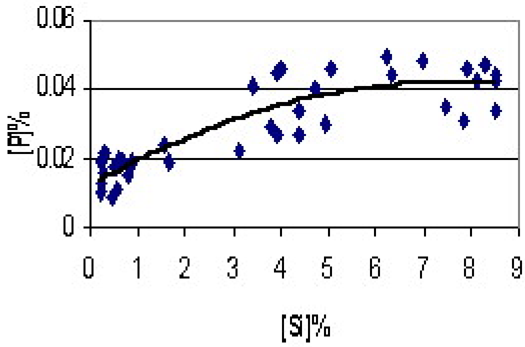

Figure 5. Metal %P content vs. %Si

3.4 Carbon content of metal

Reduction at lower temperatures with a high MgO/Al_2O_3 ratio means more and more high carbon bearing carbide are formed. The presence of chromium carbides such as Cr_3C_2 and Cr_7C_3 with less $Cr_{23}C_6$ present could be a good indication of solid state reduction of the ore.

Cr/Fe ratio should play a role in the determination of the carbon content of the alloy. As chromium has more affinity to form carbides than iron, a higher Cr/Fe ratio means a higher carbon content of metal.

3.5 Si

A high MgO/Al_2O_3 ratio and a basic slag inhibit reduction of SiO_2 to Si. Higher temperatures are required for the reduction of SiO_2. Cr_2O_3 and FeO are reduced in solid state and in lower temperatures, thus there is very little opportunity for SiO_2 to be reduced.

Again a low Si content is a result of reduction of Cr_2O_3 and FeO in solid state and low temperatures.

3.6 S and P

Since the S and P content of the chrome ore is very low, introduction of S and P to metal is predominantly from the reductants. A coke with a sulphur content of 0.6 to 1 percent will deliver a metal with a sulphur content of 0.014 to 0.025. For desulphurisation, basic slags[6], a reducing environment and higher temperatures with respect to dephosphorization are necessary. These conditions do exist.

For dephosphorization the requirements include basic slags, lower temperatures and an oxidizing environment. From all of these, only a basic slag could be established. An increase in the Si content of the metal is an indication of a reducing environment (Figure 5). Even though most of the phosphorous enters the metal, the high basicity of the slag could result in a decrease in phosphorous content.

Sum of the alloy's carbon and silicon contents has a negative correlation with the sulphur inside the alloy. In fact C and Si both are reducing agents and can meet one of the above conditions.

All of the above help to use cheaper reductants higher in S and P content. The P content of the alloy is 0.010 - 0.025 (Table 2).

3.7 Slag characteristics

Slag composition under normal conditions has no big influence on slag Cr_2O_3 content. We have used different fluxing agents including silica, lime and aluminium bearing materials to adjust other slag properties like viscosity, solidification range, melting point and electrical conductivity. The average Cr_2O_3 content in the slag was 2.6 percent during the period under study.

An high silicon content in the alloy can reduce Cr_2O_3 dissolved in the slag by a silicothermic reaction and in turn the Si content of metal decreases, but this reaction is only significant at high Si contents. At this condition the colour of slag will become lighter.

Generally we could not see any metal and chrome ore entrapped in the slag. If the Cr_2O_3 content in the ore was high, some chromite was not totally reduced and could be observed in the tapped slag.

Table 2. High carbon and extra high carbon ferrochrome chemical analysis.

Item	Chemical Analysis, Mass%			
	High carbon FeCr		Extra high carbon FeCr	
	Range	Average	Range	Average
Cr	63.22 – 69.84	67.03	65.56 – 69.86	67.86
C	7.51 – 8.99	8.64	9.00 – 9.47	9.17
Si	0.22 – 2.91	0.99	0.29 – 1.34	0.65
S	0.009 - 0.040	0.0213	0.009 – 0.037	0.0198
P	0.007 – 0.024	0.0143	0.011 – 0.020	0.0165

4. CONCLUSIONS

There is an optimum range for the reducibility of the Iranian ore. The MgO/Al_2O_3 ratio is directly proportionate to the Cr_2O_3 in the slag. The optimum for Iranian ore is an ore with a Cr_2O_3 content between 43 and 46 percent and MgO/Al_2O_3 between 2.2 and 2.5. In this range the Cr recovery is 95 percent and the energy consumption is the lowest.

The analysis also showed that the lowest cost of production could be achieved using the ore with the mentioned specification. This analysis could be used for different ores or a blend of ores, if we know their mineralogical and metallurgical behaviour.

5. REFERENCES

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