CHINA'S ENVIRONMENTAL TARGETS FOR SUSTAINABLE GROWTH AND THE TECHNOLOGICAL CHALLENGES FOR THE FERROALLOYS INDUSTRY

[1]Mikael Louhi, [2]Patrick Tang

[1]Outotec (Finland) Oy, Espoo, Finland, e-mail: mikael.louhi@outotec.com
[2]Outotec China, Beijing, Peoples Republic of China, e-mail: Patrick.tang@outotec.com

ABSTRACT

With steel and stainless steel consumption in China rising at a rapid pace and China's share of global ferroalloys production continuously increasing, the environmental aspects of upstream and downstream production processes have to be taken in to account as the need for ever more sustainable growth is being stressed.

In response to the demand for sustainable growth China has issued its greenest five-year plan ever and new standards for ferroalloy production technologies and their emissions have been put in to practice.

The environmental protection ministry has set strict standards for the ferroalloy industry. Meeting these standards, for example for ferrochrome furnaces larger than 50 MVA; charge grade above Cr_2O_3 40%, power consumption in smelting below 2 800 kWh/t (Cr50 %), recovery above 92% and a comprehensive energy consumption converted into standard coal equivalents (SCE) per ton of metal below 740 kg. These figures are impossible to achieve even with advanced pretreatment technologies for the ore. Corresponding figures for semi-closed furnaces (12.5 – 25 MVA) are 3200 kWh/t (Cr50 %), recovery above 90 % and comprehensive energy consumption below 810 kg SCE per ton of metal. Reports show that average real power consumption without preheating and without pellet feed for closed furnaces is some 3800 kWh/t and a theoretical comprehensive energy consumption in SCE close to 1000 kg/t. A fact that has to be kept in mind is that the operational and consumption values largely depend on the type of ore that is used in the process.

Assuming good quality feed materials, pelletising & sintering and preheating of the feed for a closed furnace can bring down the power consumption in the smelting furnace close to 3000 kWh/t metal (2680 kWh/t by Cr50 % and a 56 % Cr content in the FeCr) and the comprehensive energy consumption, if only considering the preheating and smelting process below 800 kg SCE/t. With pelletising and sintering the comprehensive energy consumption amounts to some 850 kg SCE/t.

KEYWORDS: *Chinese standard for ferroalloy production, ferrochrome, emissions, environment.*

1. INTRODUCTION

As figure 1 illustrates, the carbon steel consumption per capita in China is already on the same level or above levels in some western countries, but the stainless steel consumption is lagging behind. This can be explained by the large scale, steel demanding infrastructure development taking place in China. The stainless steel consumption relates more to consumers looking for comfort and luxury. Consequently, the SS consumption in China is set to continue its increase.

The ferroalloys industry is closely linked to the stainless steel production, since a large part of the ferroalloy products are used in the stainless steel production.

In 2011 China's ferroalloys output was 28.4 mt, a 22.7 % yoy increase. The first half of 2012 also saw a 9.3 % yoy increase in output. Chinese ferroalloy production capacity is about 43 mt, and with some 30mt production in 2012 it shows a capacity utilization grade of 70 %. China's share of global ferrochrome production is expected to surpass South Africa's 1/3 in 2013. A transformation of the Chinese ferroalloy industry is inevitable; consolidation and elimination of excess capacity will be needed.

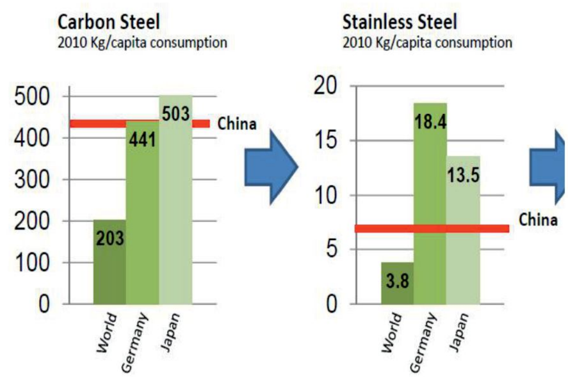

Figure 1: Carbon steel and stainless steel consumption per capita (WSA, ICSG, World Stainless Steel Statistics, Brook Hunt)

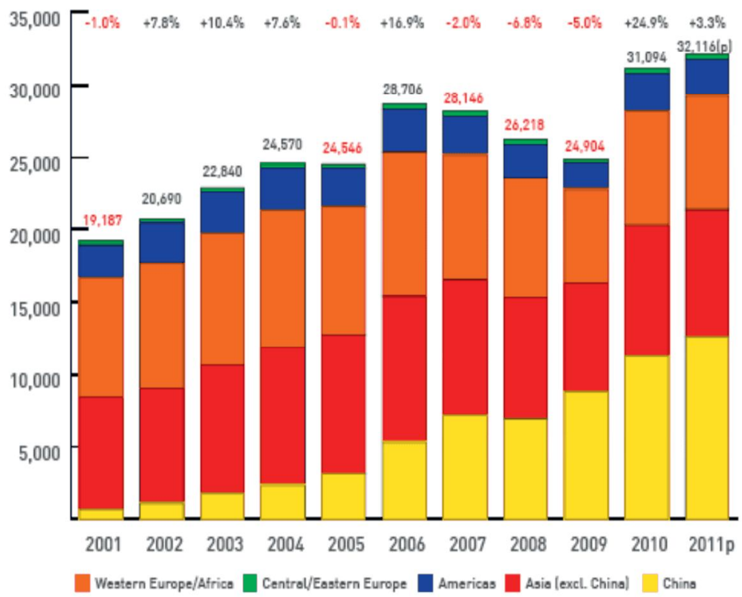

Figure 2: World stainless steel consumption (ISSF 2012)

In response to the demand for sustainable growth China has issued its greenest five-year plan ever. It includes measures to reduce pollution, increase energy efficiency and ensure a stable, reliable, and clean energy supply.

The several binding targets embedded in the plan show that the government understands how expensive and counterproductive resource-intensive large infrastructure projects are for China's future growth, as well as the government's recognition of the value of developing a low-carbon economy.

Currently, over 1500 ferroalloy furnaces with a production capacity about 40 million tons of ferroalloys can consume about 160 billion kWh of electricity on a yearly basis. On average these small units are 12.5 MVA and emit millions of tons of toxicants. Small units will be replaced by bigger ones that are more energy-efficient and low in terms of overall emissions. Local governments will favor higher capacity and more environmentally friendly units and this leads to Chinese ferroalloys producers having to look for more energy efficient technology.

This paper will attempt to interpret China's current production and emission standards for ferroalloys and how the currently available technology can respond to the figures set forth in the standards. The figures presented in China's standards will be compared to experiences from the ferrochrome industry, the Best Available Techniques (BAT) [1] report by compiled by the Integrated Pollution Prevention and Control (IPCC) directive of the European Commission (EC) and the Life Cycle Inventory (LCI) of primary Ferrochrome production by the International Chromium Development Association (ICDA) [2]. The BAT report assesses production techniques for all ferroalloys, but in some aspects generalizes the different production processes in terms of emissions, as the emissions reported are average figures for several production technologies. The LCI report on the other hand reports specific figures for different ferrochrome production technologies, but with some limitations to the accuracy as all participating companies have not validated all data. The comparisons made in this paper will to some extent be based on assumptions and generalizations. For instance China's ferrochrome production relies heavily on imported chromite ore and mixing of different chromites will affect process conditions in the smelting furnace. However, the outcome should give an indicative picture of the situation.

2. CHINA'S ENVIRONMENTAL TARGETS AND PRODUCTION AND EMISSION STANDARDS

Key targets for environment and clean energy, 2015 targets

Environment & clean energy:

- Non-fossil fuel to account for 11.4 percent of primary energy consumption.
- Water consumption per unit of value-added industrial output to be cut by 30 percent.
- Energy consumption per unit of GDP to be cut by 16 percent.
- Carbon dioxide emission per unit of GDP to be cut by 17 percent.

The ferroalloys industry will be affected especially by the targets for energy consumption and carbon dioxide emission. The central government has set strict regulations and guidelines for existing and new ferroalloy plants and thus energy in-efficient and polluting smelting plants based on conventional technology are forced to respond to the new regulations by rebuilding or shutting down the furnaces.

Already in 2009 the Environmental Protection Ministry issued the "Cleaner production standard – Ferroalloy industry, HJ 470-2009. The standard defines the technical requirements for ferrosilicon, ferromanganese and ferrochrome production processes. In 2012 an emission standard of pollutants for ferroalloy smelt industry, GB 28666 – 2012, was issued.

The production process and equipment requirements are classified according to the size of the furnaces; ⩾ 50 MVA, ⩾ 25 MVA and ⩾ 12.5 MVA. Larger production units will be favored for future project as they contribute positively to cost and energy efficiencies.

Key figures from the standards for large greenfield high carbon ferrochrome furnaces (⩾ 50 MVA) are listed in table 1. Figures related to emissions are given for ferroalloy plants located in areas that already are polluted heavily, or in a weak ecological environment.

It can be concluded that certain requirements and figures in the aforementioned standards are extremely strict and some very difficult to achieve in practice.

2.1. Clean ferroalloy production standard

The electricity consumption for a smelting process largely depends on the type of ore that is used in the process and on the type of pretreatment for the ore. According to the Chinese standard for ferrochrome production the allowed electricity consumption depends on the grade of the charge ore and the Cr-content of the end product. With a charge grade of 40 % Cr_2O_3 an electricity consumption of 2800 kWh/t (Cr 50 %) is allowed. Every 1 % of the grade of the charge ore reduces or respectively increases the allowed electricity consumption by 80 kWh/t. For example if the FeCr contains 56 % Cr and assuming a Cr/Fe ratio of 2, it would require a Cr_2O_3 grade of some 44 % which translates in to an allowed Cr 50 % electricity consumption of 2480 kWh/t and a real electricity consumption of 2800 kWh/t. A typical closed furnace with a cold lumpy ore feed has an electricity consumption of 3800 kWh/t of metal. The electricity consumption in smelting can be lowered closer to the required level with a preheated pellet feed for a closed submerged arc furnace.

Table 1: Key figures from Chinese standards for ferroalloy production

Production technology, resource and energy use, recycling		
		HC FeCr
Rated capacity, MVA		⩾ 50
Furnace type		Closed
Gas cleaning equipment		Dry
CO gas recycling		Recycle gas for reuse
Grade of ore, %		Cr_2O_3 content ⩾ 40
Recovery rate, %		⩾ 92
Electricity consumption, kWh/t (Cr50%)		⩽ 2800
Comprehensive energy consumption (standard coal equivalents)		⩽ 740
Reuse rate of industrial water, %		⩾ 95
Gas recycling rate, %		100
Utilization rate of furnace slag, %		100
Dust recycling rate, %		100
Atmospheric emissions at stack, (mg/Nm^3), upper limit		
Particles		20
SOx		100
NOx		300
Cr and Cr compounds		3
Atmospheric emissions at plant boundary, (mg/Nm^3), upper limit		
Particles		1
Cr and its compounds		0.006
Emissions to water, discharge at plant boundary, (mg/l), upper limit		
Cr6		0.5
Total Cr		1
Cyanides		0.5

The recovery rate of 92 % is unprecedented from a SAF without prereduction before smelting. Recovery rates above 90 % can be achieved with a DC furnace, but the drawback with the DC furnace is that the electricity consumption is higher. Average electricity consumption for a DC furnace for FeCr production are reportedly above 3 500 kWh/t, so for instance achieving the 2800 kWh/t Cr 50 % would require the charge grade of 40 % Cr_2O_3 to produce a FeCr with a Cr content of 63%, which in turn would require a chromite with a very high Cr/Fe ratio.

According to the standard the limit for comprehensive energy consumption for ferrochrome production (⩾ 25MVA), calculated by formula (1) is 740 kg SCE/t.

$$E_{THJ} = \frac{e_{yd} + e_{th} + e_{dl} + e_{yr}}{P_{THJ}} \quad (1)$$

Where,
E_{THJ} = Comprehensive energy consumption of ferroalloy products (converted standard coal) kg/t;
e_{yd} = Electric energy consumption per year in ferroalloy production (converted standard coal) kg;
e_{th} = Carbon reductant consumption per year in ferroalloy production (converted standard coal) kg;
e_{dl} = Dynamic energy consumption per year in ferroalloy production (converted standard coal) kg;
e_{yr} = Yearly secondary energy recovery and external supply (converted standard coal) kg;
P_{THJ} = Production of yearly qualified ferroalloy, t.

In Chinese aggregate energy statistics electricity is converted at a "standard" value of the amount of primary energy consumed in power plants to produce a kWh of electricity (0.404 kg of standard coal equivalent). However, the Chinese ferroalloy standard advises that conversion from electricity to SCE is to be done by 0.1229 kg/kWh.

Industry experience, the ICDA LCI report and the EC Best Available Techniques summarize average electricity consumption levels for closed furnaces without preheating and without pellet feed to some 3800 kWh/t, which equals 467 kg SCE/t. The average reductant feed is some 600 kg/t, with Chinese coke with a C_{fix} of 82 % equals 492 kg C/t. Chinese practice assumes that 1 kg of coke contains 0.9714 kg of SCE and this sums the amount of reductants consumed to some 583 kg SCE/t.

The volume of CO gas produced in the reduction of one ton of ferrochrome in a closed furnace is about 650 - 750 Nm^3 with a reaction energy of 2100 – 2300 kWh [3]. This figure relates to the smelting process with preheated pellets hence for this process the average value of 2200 kWh is used.

For the smelting process without preheating and without pellets a slightly lower amount of CO gas is produced per ton of ferrochrome, since without preheated pellets the production from the same size furnace is lower and the CO content of the CO gas is lower. Some 2100 kWh of reaction energy from the produced CO gas is assumed.

In the case of energy recovery the most efficient technique is considered in this calculation. Internal combustion engines have the highest efficiency in terms of producing electricity from the furnace CO gas, some 35 %. With the above mentioned electricity consumption and assuming 1 kWh equals 0,1229 kg SCE some 90 kg SCE can be deducted from the comprehensive energy consumption. In spite of disregarding the dynamic energy consumption for a typical closed furnace without preheating and without pellets the comprehensive energy consumption amounts to 960 kg SCE/t, which is above the limit of 740 kg SCE/t.

The clean ferroalloy production standard requires dry gas cleaning for the furnace off-gas. From an environmental point of view this requirement is understandable as wet scrubbing consumes water and requires water treatment. However, in practice off-gas cleaning for closed furnaces is done by wet scrubbing due to high temperature of off gas and wet scrubbing also enables a stable furnace operation and minimizes the safety hazards in handling the poisonous and explosive CO gas. The standard also requires a 100 % recycling rate for the furnace gas, slag and dust. An ultimately perfect process, a flawless operation would constitute recycling rates of 100 %. However, industrial processes will always have flaws. In other words, total recycling is not plausible.

2.2. Emission standard

Atmospheric emissions for particulates at the stack of a green field production facility in a polluted area are given an upper limit of 20 mg/Nm^3. The BAT statistics report average particles emissions to air of 50 mg/Nm^3 for HC FeCr smelting furnaces. The LCI report on the other hand indicates a range of 92 - 14 615 mg/Nm^3 (60 - 9500g/t at 650 Nm^3/t) for the closed FeCr smelting furnace without preheating and without pellet feed. The high end of the range is clearly an exception, as the same report indicates that for a closed furnace with preheating the corresponding figures are 6 – 357 mg/Nm^3 (4 - 250g/t at 700 Nm^3/t). Existing technologies can curb particulate emissions to required levels.

The SO_x and NO_x emissions will largely depend on the raw material and reductants used and the definition of the production facility. The emission standard stipulates 100 mg/Nm^3 for SO_x and 300 mg/Nm^3 for NO_x from the stack. According to the BAT report the SO_2 emission for HC FeCr production ranges between 0.2 - 3 kg/t and the NO_x ranges between 0.5 – 1.5 kg/t. These figures refer mainly to the pelletising and sintering process with oxidizing conditions in the furnace, where the burning of coke generates SO_2 emissions (0.2 - 0.3 kg/t pellets [3]) and the firing generates NO_2 emissions (0.3 – 0.7 kg/t pellets [3]). The closed smelting furnace the off-gas has a typical composition of 75-85 % CO, 5 % H_2. The dust contains mainly SiO_2, MgO, Zn and C, and smaller amounts of Cr, Fe, Al_2O_3 and CaO.

According to the BAT report the Cr^{6+} content of the furnace dust is between 5 - 100 ppm in the closed furnace and between 1000 - 7000 ppm in the open furnace. Sampling of the process water from off-gas scrubbers of a closed furnace at a reference plant indicates a Cr^{6+} content of less than 0.01 mg/L. The amount of gaseous cyanides formed in the closed smelting furnace is reported to 0.02 – 0.05 kg/t FeCr. These components are transferred to the gas cleaning water and if the same water is circulated to granulation basically all cyanides evaporate and oxidize in the process.

3. TECHNOLOGY SOLUTION TO MINIMIZE ENVIRONMENTAL IMPACT

China has over 1500 ferroalloy furnaces, a large part of them small and open or semi-closed. The current capacity will be consolidated to fewer production facilities and new larger units will be constructed. In order to meet the Chinese standards for ferroalloy production the performance of the widely applied pelletising&sintering and preheating&smelting process for FeCr is here evaluated against the environmental requirements. Certain values presented are reported from a reference plant and may differ from figures measured at other production facilities, this especially depending on types of ores and reductants used. Certain values are based on theoretical calculations assuming a 100% pellet feed with a mixture of chromites that have a Cr/Fe-ratio of 2.

3.1. Electricity consumption

In terms of saving electric energy in the smelting furnace the prereduction of chromite is the most attractive option, since prereduction can reduce the electricity consumption in smelting more than preheating can. Prereduction done in a rotary kiln can reduce the electricity consumption in the smelting furnace to below 2500 kWh/t FeCr. The rotary kilns produce high dust contents in the off-gases and if coal with high sulphur content is used the SO_2 emissions are increased. The total amount of reductants for rotary kiln prereduction and closed furnace smelting remain on the same level or higher. The electricity consumption for the rotary kiln and auxiliaries also even out the benefit.

Assuming a final product with 56 % Cr content requires a charge grade of 44 % Cr_2O_3, which gives and allowed electricity consumption of 2480 kWh/t Cr 50 %. The allowed real electricity consumption would thus be below 2800 kWh/t. Pelletising & sintering and preheating the feed before smelting it a closed furnace will bring down the electricity consumption for the smelting furnace closer to 3000 kWh/t FeCr (369 kg SCE/t).

3.2. Comprehensive energy consumption and gas recovery

The pelletising and sintering plant consumes some 70 kWh/t FeCr (9 kg SCE/t) and the preheating kiln consumes some 50 kWh/t FeCr (6 kg SCE/t). The addition of the PSP and preheating stages will add some 120 kWh/t FeCr to the overall process, thus bringing the total electricity consumption to about 3120 kWh/t FeCr. In measures of SCE total electricity consumption amounts to 383 kg/t.

Fine coke is added to the pelletising and sintering process (PSP) of which the amount is 40 kg/t FeCr (39 kg SCE/t). CO gas from the smelting furnace is used as fuel both in the PSP and the preheating (PH) and will thus be classified emission free. The amount of reductants (Chinese coke) in the smelting process (SAF) is 500 kg/t FeCr (486 kg SCE/t). Process gases from the pelletising and sintering plant are not reused, since they contain no heating value. From the preheating kiln some 500 Nm^3/t FeCr exits at the stack, also containing insufficient heating value.

The CO gas produced in the smelting furnace is used as far as possible due its high energy content. The gas is cleaned in high pressure wet scrubbers and further cleaned in a filter. Some 5 % is flared for optimal process control and the remaining 95 % of the produced CO-gas is recycled. Some 30 % of the gas is used for the pelletising & sintering plant and preheating thus 65 % of the produced CO gas being available for power generation. In this comparison the CO gas is assumed to be used with an electricity conversion efficiency of 35 %. With a reaction energy of 2 200 kWh the theoretical energy recovery is 462 kWh (62 kg SCE/t). Without the dynamic energy consumption the comprehensive energy consumption amounts to 845 kg SCE/t FeCr.

3.3. Water and slag

The pelletising and sintering plant has its own water treatment system and all waters will be recirculated. The process dust is captured into the slurry from the cascade scrubbers and it can be circulated back to the process, enabling close to a 100 % dust recycling rate.

For the smelting plant a closed water treatment system consisting of a thickener and settling ponds allow a high recirculation degree of the process waters. Close to 90 % of the waters can be recirculated. The smelting furnace dust is captured into the slurry from the furnace scrubbers, but it is not suitable for recycling and is therefore dumped. This results in a total dust recycling rate of 80 % from the process. The granulated slag from the smelting plant is chemically stable and can be used for road and construction works. Up to 95 % of the slag can be used. According to Finnish standards SFS – EN 13242 and SFS 5904 the ferrochrome slag is an approved commercial product.

3.4. Emissions

The amount of off-gas generated by pelletising and sintering process is depending on the capacity of the plant some 2500 –4500 Nm^3/t pellets. Reported dust emissions are some 5 – 50 mg/Nm^3. Reported SO_2 emissions are some 0.2 – 0.3 kg/t pellets and NO_2 emissions some 0.3 – 0.7

kg/t pellet, meaning that the SO_2 emissions are below 100 mg/Nm^3 and the NO_2 emissions below 300 mg/Nm^3 [3]. The preheating process off gas is reported to contain some 5 – 10 mg/Nm^3 of solids and a small amount of NO_2. The smelting process is reported to generate some 50 – 100 mg/Nm^3 of solids. The smelting furnace off gas is cleaned in high pressure wet scrubbers where after it is further cleaned in a plate filter. This filter can bring down dust contents to 5 mg/Nm^3.

Chromium compounds and cyanides are difficult to measure since they largely depend on the production process and water treatment facilities. Total amount of chromium compounds in the closed smelting furnace process dust is below 2%, of which the hexavalent chromium content is 5 – 100 ppm. The amount of gaseous cyanides in the closed furnace is some 20 – 50 g/t FeCr and these compounds will be transferred to the gas cleaning water and water treatment plant and will be circulated to slag granulation where basically all cyanides evaporate and oxidize. A Finnish reference plant has reported that after water treatment where a thickener, slag granulation and settling ponds are used the emission of total Cr was about 3 – 5 g/t FeCr and cyanides 0.3 – 1.5 g/t FeCr.

3.5. Comparison of Chinese standard and existing production technology

From an environmental point of view the pelletising & sintering and preheating & smelting process is summarized in table 2.

Table 2: Comparison of Chinese standard and existing FeCr production technology. The presented figures are averages

Production technology, resource and energy use, recycling		
	HC FeCr	HC FeCr
Rated capacity, MVA	⩾ 50	⩾ 50
Furnace type	Closed	Closed
Gas cleaning equipment	Dry	Wet
CO gas recycling	Recycle gas for reuse	Recycle gas for reuse
Grade of ore, %	Cr_2O_3 content 44	Cr_2O_3 content 44
Recovery rate, %	⩾ 92	< 90
Electricity consumption, kWh/t (Cr50%)	⩽ 2480	2680
Comprehensive energy consumption (standard coal equivalents)	⩽ 740	845
Reuse rate of industrial water, %	⩾ 95	90
Gas recycling rate, %	100	95
Utilization rate of furnace slag, %	100	95
Dust recycling rate, %	100	80
Atmospheric emissions at stack, (mg/Nm^3), upper limit		
Particles	20	25 (PSP), 7 (PK), 5 (SAF)
SOx	100	< 100
NOx	300	< 300
Cr and Cr compounds	3	0.1
Atmospheric emissions at plant boundary, (mg/Nm^3), upper limit		
Particles	1	n.a.
Cr and its compounds	0.006	n.a.
Emissions to water, discharge at plant boundary, (mg/l), upper limit		
Cr^6	0.5	0.01
Total Cr	1	> 1
Cyanides	0.5	< 0.5

A 100 % pellet feed with Cr/Fe-ratio of about 2 is assumed, with a charge grade of 44 % Cr_2O_3 and a FeCr with a Cr content of 56 %. PSP = pelletising and sintering plant, PK = preheating kiln, SAF = submerged arc furnace.

4. SUMMARY AND CONCLUSIONS

Chinese standards for ferroalloy production and emission limits are very strict. The central government has put in to place limits that require advanced technological solutions to meet the requirements. A simplified comparison of requirements versus available production technology shows that there still is room for improvement when it comes to minimizing the environmental impact. Setting strict targets will enforce improvement and development of existing technologies in order to meet regulations.

The presented figures for FeCr production reveal that even theoretically optimal calculations have difficulties in complying with the standards. Reported figures from a reference plant that operates a technologically advanced production process exceed a large part of target values or doesn't comply with the requirements. The correctness of presented figures can be questioned, for example in the case of dust emissions. Reports from the industry reveal a wide range of dust content in off gases. Also average electricity consumption and recovery rates seldom are on the same levels as they optimally can be. A 100 % sintered pellet feed with high Cr/Fe ratio chromites enables near compliance with requirements set forth in the Chinese standards. Replicating existing outside China plants in a Chinese environment is not a simple task, but if similar production technologies are applied the environmental impact the ferroalloy industry currently has in China can be diminished.

5. REFERENCES

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