Effect of South Africa Reductants on Ferrochrome Production

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ABSTRACT: With a limited supply of electricity, and sharp increase of electricity tariffs, South Africa's share of world ferrochrome production has declined to 38% in 2011. The situation is set to continue and could go from bad to worse in the near future. Consequently, all ferrochrome producers in South Africa are looking for any alternatives that can use less electricity. An investigation of the effect of various reductants on the electric energy consumption is under consideration.

A group of reductants, consisting of 6 types of coke and 2 types of anthracite, is selected to investigate the effect on energy consumption of ferrochrome production in submerged arc furnace. An excel-based simulation is used to calculate all charges and energy usage with similar production conditions used by most ferrochrome producers in South Africa.

Keyword: ferrochrome production, process simulation, South African reductant

1. INTRODUCTION

South Africa plays a significant role in the world's output of ferrochrome, contributing around 38% of the total in 2011[1]. Recently, the mining industry has been hit badly because of the shortage of electricity.Since 2008, Eskom (South Africa Power Utility) has increased power tariffs every year by over 20%, seen in figure 1.

Due to the shortage of electricity, major ferrochrome producers in South Africa have entered into an agreement with Eskom for reducing their production capacity. Consequently the South Africa's share of total production of ferrochrome decreased, seen in figure 2 [1]. With a limited supply of electricity and sharp increase in electricity cost, all ferrochrome producers in South Africa are looking for any alternatives that can use less electricity. An investigation of the effect of various reductants on the electric energy consumption is one of those considerations.

Most ferrochrome producers in South Africa have its own mining operations and are located near the Bushveld Igneous Complex, in Rustenburg, Brits, Witbank, Lydensberg, and Steelpoort. Those producers include Xstrata, Samancorcr, Hernic, SAS Metals, Assmang Chrome, Mogale Alloys, etc.All the chrome ore in South Africa is located in the Bushveld Igneous Complex.

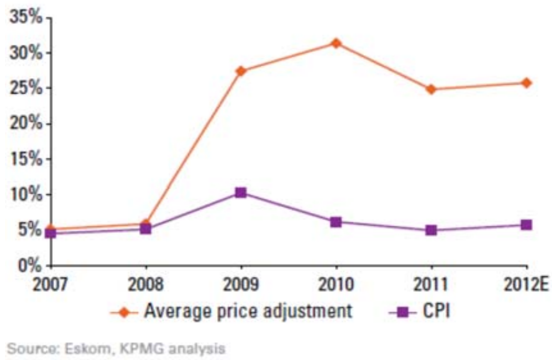

Fig. 1. Electricity tariffs increase in South Africa since 2007[1]

According to Cramer et al [2] South Africa's chrome reserves probably exceed 75% of the world's economical resources. The latest survey by United States Geological Survey (USGS) [3] cites the world resources of chromite as being greater than 12 billion tones of shipping-grade chromite and about 95% of the world's chrome resources are geologically concentrated in Kazakhstan and southern Africa. The shipping-grade chromite ore is defined by USGS as the deposit quantity and grade normalized to and above 45% Cr_2O_3.

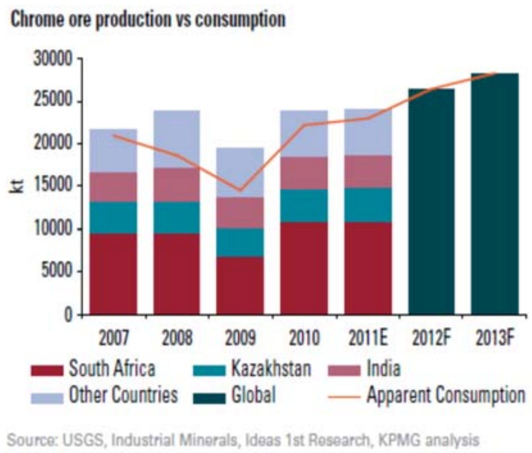

Fig. 2. Demand and production of ferrochrome worldwide

2. REDUCTANTS USED IN SOUTH AFRICA

South Africa has been self sufficient for many years with respect to reductants for the production of ferro alloys. However, in recent years it has become necessary to import metallurgical coke, most from China, used mainly for ferrochrome production [3]. The reasons for this can be ascribed to the rapid increase in ferro alloy production capacity, no growth in coke production capacity in South Africa in recent years and the trend towards closed furnaces, mostly for environmental reasons. Closed furnaces or large furnaces in general require more coke. There has also been a tendency to increase the usage of anthracite in ferro alloy production. Application of anthracite has been mainly in DC furnaces and small AC submerged arc furnaces.

South Africa's coke is produced by heating coal blend in the absence of oxygen to about 1100 ^{0}C. The quality and properties of coke are affected by the coal properties, such as coal-rank; fluidity; chemical composition; mineralogical structure and conditions of coke-making process.

In general, coke used in electric submerged arc furnaces is required to have high carbon content, low contents of phosphorous and sulfur, right size, high reactivity, good strength and proper electrical resistivity [4]. The typical properties of reductants used in production of charge chrome (ChCr) in South Africa are listed in Table 1 [3].

South Africa's coal is most mined in Ermelo and Witbank basins. Coal used for metallurgical purpose is mainly from Witbank basin, located between Pretoria and Nelspruit, see in figure 3.

Table 1. Typical properties of selected carbon reductants used in charge chrome production

Property	Coal	Anthracite	SA ChCr coke	Chinese ChCr coke
Volatile %	18-25	6-10	<1	<1
Ash%	11	15	16	14
Fixed carbon%	56	80	83	85
S %	0.8	0.6	0.7	0.6
P %	0.009	0.004	0.009	0.013
Reactivity	n/a	23.1	45.4	23.90

Coke is made by various suppliers in various locations, including Mittal Coke & Chemicals, Xstrata and Kumba Resources, etc. Five types of coke and two types of anthracite plus one coke from China are selected for the investigation. The composition can be seen in Table 2.

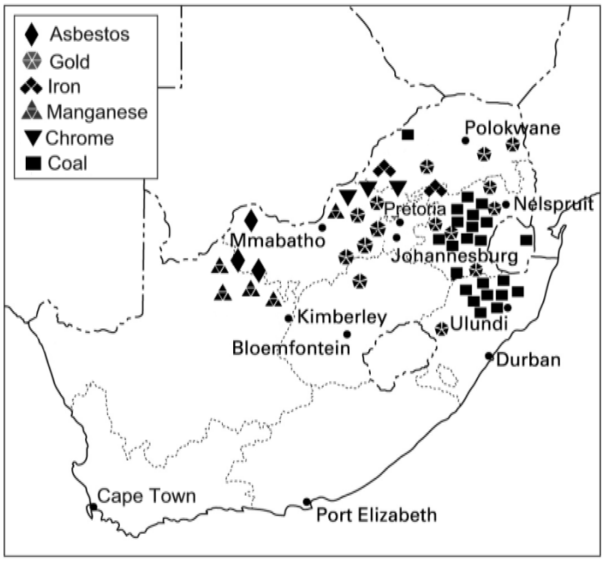

Fig. 3. Mining operations in SouthAfrica, including Asbestos, Gold, Iron, Manganese, Chrome, and coal

Table 2. Chemical composition of coke nuts and anthracites in %

Reductants	F.C	Volatiles	H2O	S	P	FeO	SiO2	CaO	MgO	Al2O3
Wankie Coke	85.1	1.6	2.6	0.9	0.028	0.9	3.7	0.9	0.1	4.3
Pretoria Coke	78.4	1.4	5.8	0.7	0.01	0.21	10.4	0.3	0.2	3.5
Newcastle Coke	78.17	0.73	3.63	0.69	0.007	1.6	10.5	0.5	0.2	4.3
Green Maceral Anthracite	82.3	4.7	2.6	0.66	0.003	0.58	6.3	0.08	0.17	2.88
Vanderbiji Coke	83	1.2	3.2	1	0.011	0.68	6.7	0.28	0.7	3.92
Mpofeni Anthracite	79.1	5.5	3.3	0.85	0.006	1	6	0.2	0.2	4
Vryheid Coke	75.4	0.7	2.1	0.57	0.008	0.9	14.8	0.2	0.2	5.4
Chinese Coke	79.1	1.5	2.7	0.73	0.009	0.44	8	0.17	0.7	7.1

3. SIMULATION OF HCFeCr PRODUCTION

An excel-based simulation, Ferrochrome Simulation (FeCr-Sim), was used to evaluate the effect of different reductants on the electricity consumption used to produce high carbon ferrochrome (HCFeCr) in submerged are furnace, which uses electric energy and is fed with raw materials of chrome ores, fluxes, reductant and electrode paste.

The Ferrochrome Simulation is developed using the principles of mass balance and heat balance, the interface can be seen in figure 4. The simulation requires six inputs and generates the results of charge recipe, mass and composition for slag, metal, and off gas, with the energy consumption associated with the production process.

Ferrochrome Simulation Inputs:

- Compositions of ore, fluxes, reductants
- Mass of chrome ore (kg)
- FeO content in slag (%)
- Cr2O3 content in slag (%)
- Silicon content in metal (%)
- Carbon content in metal (%)

Ferrochrome Simulation Outputs:

- Charge recipe (chrome ore/quartzite/coke/anthracite)
- Mass and composition of slag
- Mass and composition of metal
- Mass and composition of off gas (with or without CO combustion)
- Electric energy consumption
- Recovery rate of Cr, Fe

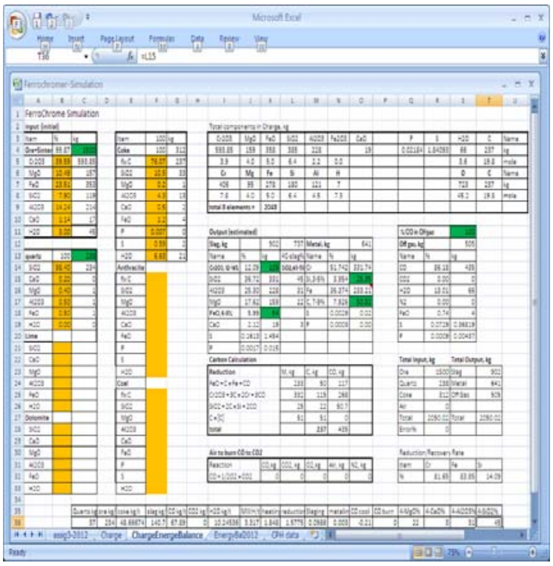

Fig. 4. Ferrochrome simulation used to calculate charge and electricity consumption of ferrochrome production in a submerged arc furnace

Five types of coke, two anthracites and one Chinese coke used as reductants for charge chrome production are used to evaluate the effect on ferrochrome production. One type of chrome ore is used, quartzite is added as flux, and coke and anthracite are used as reductant. The chemical composition of quartzite and chrome ore are listed in Table 3. Based on the production of ferrochrome smelting in South Africa, the following conditions are assumed:

- 6% FeO in slag
- 12% Cr2O3 in slag
- 45% SiO2 in slag of CaO-MgO-Al2O3-SiO2
- 8% carbon in metal
- 4% silicon in metal
- Slag temperature 1700 ^{o}C
- Metal temperature 1600 ^{o}C

Table 3. Composition of flux quartzite and reductant coke (wt %)

Name	Chrome Ore	Quartzite flux
Cr2O3%	39.59	0
FeO%	23.51	0.5
S%	0.003	0
P%	0.009	0
H2O%	3	0
SiO2%	7.9	98.4
CaO%	1.13	0.2
MgO%	10.49	0.4
Al2O3	14.24	0.5

4. RESULT AND DISCUSSION

4.1. Fixed Carbon and Non-carbon Contents

The selected cokes and anthracites contain 75-85% fixed carbon, 2-6% water, 1-6% volatile, 0.5-1% sulfur, 0.01-0.03% phosphorus and 9-20% ash. The ash consists of mainly 0.5-2% FeO, 0.1-1% CaO, 0.1-1% MgO, 3-7% Al2O3, and 4-15% SiO2. The following contents have a variance less than 5%: water, volatiles, Al2O3, CaO, MgO, FeO, see in figure 5.

The consumption of electric energy required to produce one ton of ferrochrome is in a range 3.30 to 3.34 mwh/t, when the selected 8 different reductants are used. The lowest energy consumption of 3.30 mwh/t can be achieved when using Wankie coke nuts. The highest energy consumption is required when using the selected Chinese coke nuts, seen in figure 6.

The effect of fixed carbon on electric energy consumption is drawn in figure 7. There is no clear indication to show a close relationship with the selected reductants. A similar result is obtained for the contents of ash, volatile and water in the reductants, see in figure 8.

The primary function of carbonaceous reductants is to act as a reducing agent required to react with metal oxides to produce metal and form carbon monoxide.

The reductants also provide a source of carbon in Fe-Cr alloy. A higher content of fixed carbon will result in lower contents in total of non-carbon materials in the reductants, such as water, volatile and ash, and will definitely reduce the amount of required reductants such as coke or anthracite.

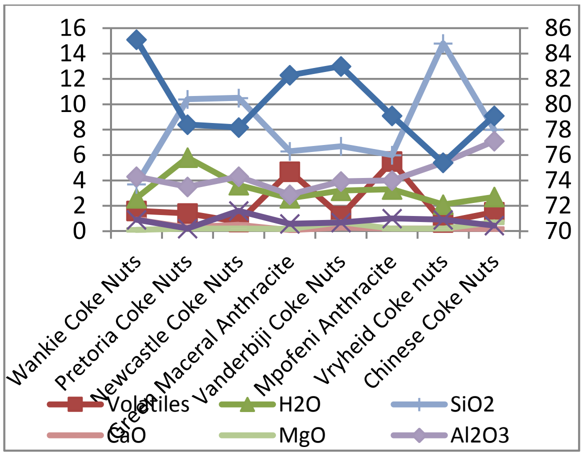

Fig. 5**.** Chemical composition of selected 6 types of coke, 2 types of anthracite, showing a variance of more than 6% with SiO2% and fixed carbon% (on right axis)

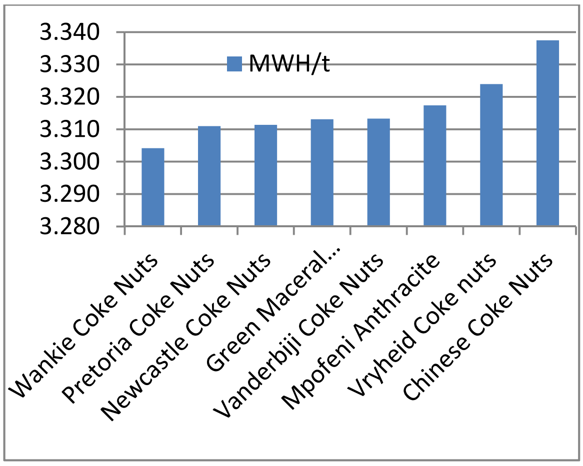

Fig. 6**.** Electric energy consumption required to produce one ton ferrochrome mwh/t when using different reductants

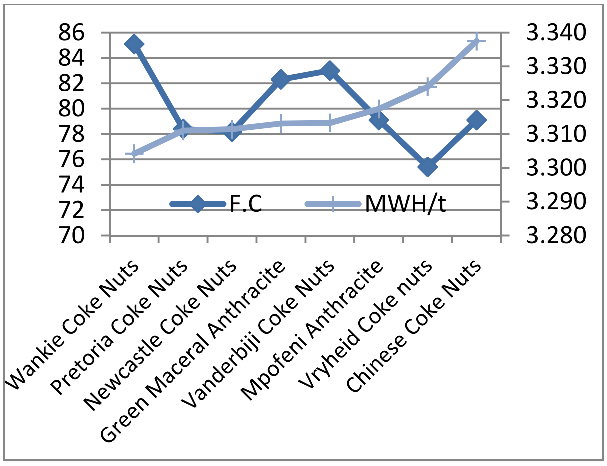

Fig. 7. Effect of fixed carbon on electric energy consumptionmwh/t (on right axis)

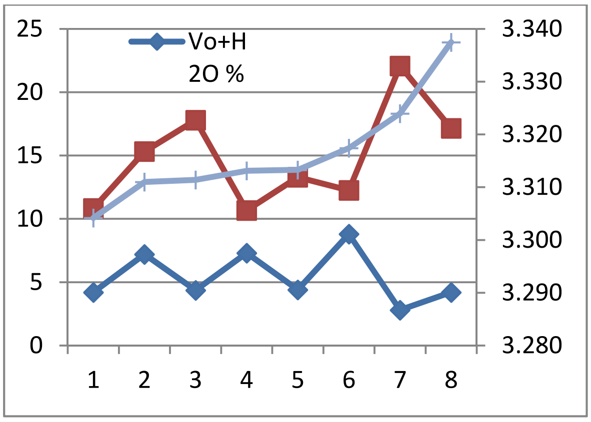

Fig. 8. Effect of ash, water and volatile on electric energy consumption mwh/t (on right axis)

4.2. Ash Composition on Energy Consumption

The ahs composition of the selected reductants includes 5-15% SiO2, 3-7% Al2O3 with less than 2% of CaO, MgO and FeO. It seems that the energy consumption of ferrochrome production rises with an increases of ash contents of both SiO2 and Al2O3, see in figure 9. Due to the fact that the SiO2 content is fixed at 45% in the slag, an increase of Al2O3 content in the ash will result in adding more flux to provide more SiO2 in the slag. A higher addition of flux/quartzite into the furnace requires more energy for heating and melting slag. However,when a reductant has a higher SiO2 content in the ash, it requires less addition of flux quartzite to obtain the required 45% SiO2 in the slag, which should result in less energy consumption.

4.3. Ash and Flux Addition

When combining the amount of ash and amount of added flux quartzite together, it depicts a very close relationship between the energy consumption and the total amount of ash and quartzite, namely the electric energy consumption in mwh/t increases with a higher amount of ash and quartzite addition in kg/t, seen in figure 10.

Considering the fact that almost all contents of ash go to slag, the higher amount of ash and flux quartzite added in the furnace, the more electric energy is required to heat and melt the ash and flux to form slag. When other contents are similar, a higher content of ash will results in a lower fixed carbon content in the reductant, which requires higher reductant consumption, seen in figure 11.

4.4. Slag Ratio on Energy Consumption

Slag formed in ferrochrome smelting contains mainly CaO, MgO, Al2O3, SiO2, FeO, and Cr2O3.The non-stable oxides will come out of the furnace in the form of off gas. All stable oxides added in furnace together with chrome ore/reductants/flux will come out of the furnace mostly in the form of molten slag, including CaO, MgO, Al2O3.

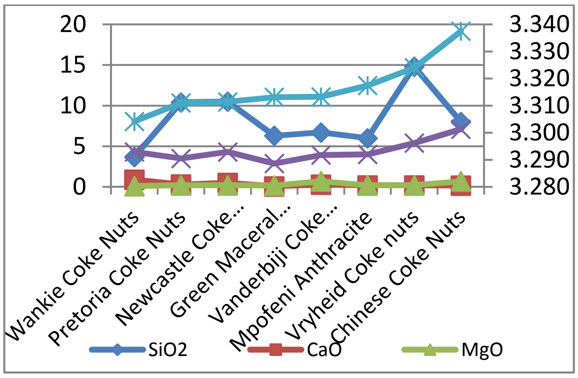

Fig. 9. Effect of ash composition on electric energy consumption mwh/t (on right axis), with low contents of CaO and MgO

When a reductant contains higher contents of MgO and Al2O3, more flux quartzite must be added in the furnace to obtain the required 45% SiO2 in slag, and consequently more electric energy must be provided. The close relationship between slag ratio kg/t and electric energy consumption can be seen in figure 12.

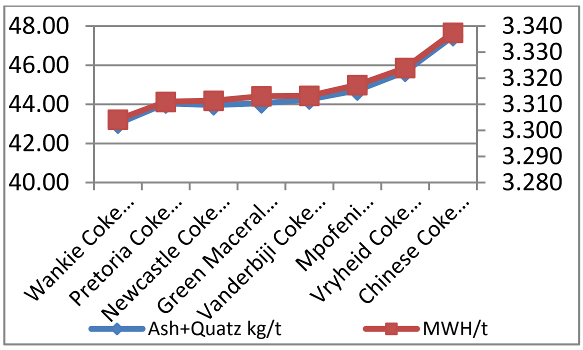

Fig. 10. Effect of total amount of ash and flux quartzite on electric energy consumption

The total consumption of electric energy can be broken into different categories, such as heating charge, reduction of oxides, forming molten slag and metal. Among the three categories, heating and reduction require the most electric energy, about 97% of the total electric energy. The energy used for heating and reduction counts for 52% and 45% respectively. Only about 3% of the electric energy is used to forming molten slag and liquid metal, see figure 13.

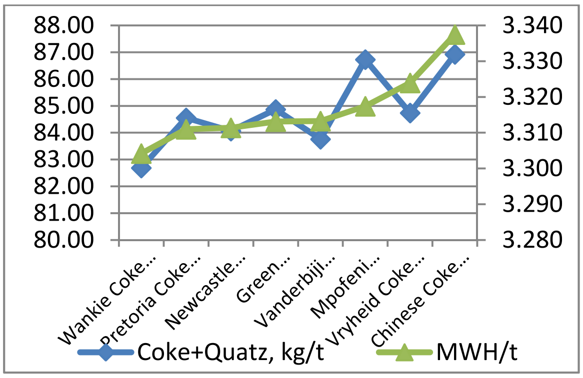

Fig. 11. Effect of total amount of reductants (coke/anthracite) and flux quartzite on electric energy consumption

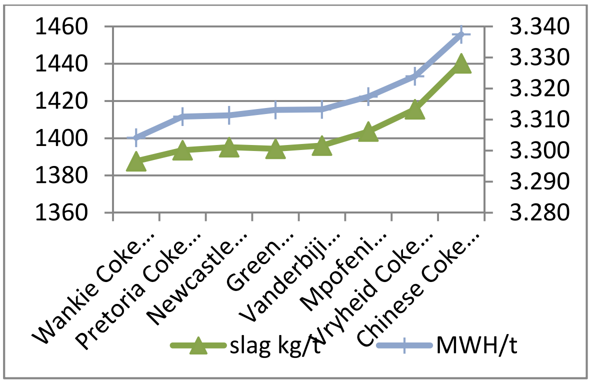

Fig. 12. Effect of amount of slag kg/t on electric energy consumption mwh/t (on right axis)

4.5. Reductant Selection for Ferrochrome Production

Reductantused for ferrochrome smelting in a submerged arc furnace traditionally includes: coke, anthracite, char/gas coke, and coal. With the challenge of rapid decrease of quality coal reserves, ferro alloy producers all over the world are forced to select and try new reductants produced from new types of coal, including bio-carbons in form of charcoal produced from different woods [5, 6].

It is a difficult task to select and use any new reductants. Not only is the chemical composition of reductant important, but the properties of the reductants for successful ferrochrome production, where main consideration must be taken such as, among others, gasification of reductant, dissolution of carbon into molten metal, and reduction of slag by solid carbon and carbon in molten metal.

Those important properties of reductants include structural order, mineralogy, reactivity with solid/gaseous/molten media, strength related to overburden pressure in furnaces, heat production during pre-reduction, electrical resistivity in the charge of electric arc furnaces. Various investigations have been conducted and reported [5, 6, 7, 8, 9], regarding reductant characterization and selection for ferroalloy production. A recent investigation of the effect of chrome ores on ferrochrome smelting has been reported [10].

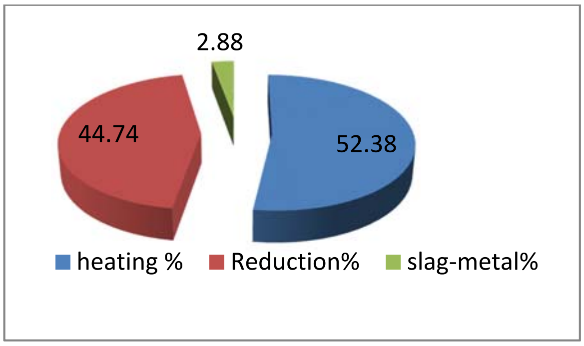

Fig. 13. Total energy consumption and its breakdown

5. SUMMARY AND CONCLUSION

A group of reductants, consisting of 6 types of coke and 2 types of anthracite, is selected to investigate the effect on energy consumption of ferrochrome production in submerged arc furnace. All selected reductants are produced locally using coals mined in South Africa, except one type of coke is from China. An excel-based simulation is used to calculate all charges and energy usage with similar production conditions used by most ferrochrome producers in South Africa, including type of chrome ores, flux, composition of slag, metal and off gas. The following conclusions can be drawn:

- The consumption of electric energy required to produce one ton of ferrochrome is in a range 3.30 to 3.34 mwh/t. The lowest energy consumption 3.30mwh/t is achieved when using Wankie coke nuts. The highest energy consumption is required when using the elected Chinese coke nuts

- There is no clear indication to show a close relationship between fixed carbon content and energy consumption among the selected reductants. A similar result is obtained for the contents of ash, volatile and water in the reductants
- The combination of ash and added flux quartzite depicts a very close relationship with the electric energy consumption, namely the electric energy consumption in mwh/t increases with a higher amount of ash and quartzite addition in kg/t

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