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Factors Affecting the Increase in the Pre-reduction Scale of the Fe-Ni Ore in the Rotary Kiln

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Abstract: The pre-reduction process in the rotary kiln is the key factor in acquiring the metal of iron-nickel from the electric furnaces.This paper's purpose is the impact of factors affecting the growth of the pre-reduction scale, and presents the factors affecting the pre-reduction scale of the iron-nickel ore in the rotary kilns in the new Foundry of the new Ferronikel in Drenas. The research was conducted in the industrial and laboratory route in the new Foundry of the new Ferronikel in Drenas through the years 2007-2014, whereas the industrial simulations of four cases were conducted in the laboratory of Fe-Ni Kavadarci-Macedonia in the laboratory kiln "Linder" in 2012. Through industrial research the average of the pre-reduction scale of the iron-nickel ore for the analyzed years exceeds 45%. Whereas, during industrial simulations the pre-reduction scale for the four analyzed charges in the rotary kilns increases by 40% in comparison to the industrial cases.

Keywords*: pre-reduction, iron-nickel, ore, rotary kiln, average, calcine, percentage.*

Introduction

The metallurgical process in the new Foundry of the new Ferronikel in Drenas, is realized by a variety of ores both imported and local. A few types are used as fuel. The compositions of ores used in the Foundry show different percentage levels of nickel, iron, humidity, and other elements. Through the years 2007-2014, oxide ore raw materials have been supplied from: Kosovo (sources Çikatova, Gllavica), Albania, Philippines, Indonesia, Turkey, and Guatemala. Ore sources in the goethite area in Gllavica, are characterized by an increase of SiO_2, the percentage of which decreases as a function of depth. This area is characterized by an increase in iron (20.23%), and a decrease of the percentage of nickel (0.51). According to the mineralogical analysis, in the nontronite area, there is an increase of MgO, the percentage of nickel (1.97%), and a decrease in the percentage of iron (13.89%). The characteristics of ore sources in Gllavica are:

High ore humidity (external)

High percentage of SiO_2 in comparison to the other ore sources used in the foundry

The percentage of iron is lower compared to the ore sources in Albania

The percentage of nickel is higher in ore sources in Çikatova. Ore sources in Çikatova, are characterized by the nontronite area, with an increase in the percentage of nickel of up to 1.45%. This area is estimated to be 10 m.Nontronite serpentines area, has a width of 3m with an average composition of nickel (1.20%). The composition of SiO_2 and FeO decreases, whereas that of MgO increases.

1. The percentage of SiO_2 is high
2. The percentage of iron is lower compared to that of ore sources in Albania
3. The percentage of nickel is lower in comparison to the ore sourcesin Philippines and Indonesia
4. The percentage of nickel is higher compared to the ore sources in Albania

Ore sources in Indonesia are characterized by the composition:

1. Of high humidity (w)
2. Of high percentage of MgO

Ore sources of the Philippines are characterized from the composition of:

1. High percentage of nickel
2. Humidity (w)
3. High percentage of iron
4. High percentage of MgO

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Ore sources of the Philippines are characterized from the composition of:

3. High percentage of nickel
4. Humidity (w)
5. High percentage of SiO_2

Albania's ore sources are characterized by a few types of ores, where the following can be witnessed:

1. High percentage of Fe
2. Lower percentage of Ni
3. Low percentage of humidity

Guatemala's ores are characterized by:

1. High percentage of SiO2
2. High percentage of Ni
3. High percentage of humidity

Of all the ores used, those from Albania's sources are characterized by a higher percentage of iron and a lower percentage of humidity

Material and methods

In order to determine the factors affecting the increase of the pre-reduction scale of the nickel ores in the new Foundry of the Ferronikel in Drenas, we have simulated the four experiments in temperatures of 800 C and 900 C, in the laboratory rotary foundry "Linder". The four ore samples and the auxiliary substance are prepared according to the industrial reports in the Foundry.

Ore percentages:

Gllavicë ore: 56.66%
Albanian ore: 20%
Filipino ore: 20%
Pieces of calcined material: 3.33%

Percentage of auxiliary substances:

Wet lignite of Kosovo: 6% and 9%
Stone coal from Indonesia: 2% and 3%

Apparatus for the removal of mechanical humidity of the sample

Initially, we have prepared four charges, in the Foundry's laboratory. The ore percentage is the same on all the charges, whereas the percentage of the auxiliary substance varies (first and third charges contain 8% of auxiliary substance, whereas the second and fourth charge contain 12% of auxiliary substance), all of the four charges have been mixed well and have been put in the laboratory kiln for the removal of the mechanical humidity (fig.1). After a stay of 8 hours, we took the slage out of the laboratory kiln, and determined the humidity for each one, while calculating the ratio between the weight of the wet and dry ore.

Figure 1. Laboratory kiln for the removal of mechanical humidity with the temperature 105-110C

Figure 2. Presentation of ore being weighed

Table.1 Chemical analysis of ore

Composition of the ore of Gllavicë (%)									
Fe	SiO_2	MgO	Al_2O_3	Ni	CaO	Cr_2O_3	Co	MnO	W
15.34	53.83	13.84	sign	1.29	0.25	0.85	0.04	0.24	32.11
Composition of the Albanian ore (%)									
Fe	SiO_2	MgO	Al_2O_3	Ni	CaO	Cr_2O_3	Co	MnO	W
28.45	33.33	3.95	1.14	0.89	1.77	2.26	0.05	0.33	12.83
Composition of the Filipino ore (%)									
Fe	SiO_2	MgO	Al_2O_3	Ni	CaO	Cr_2O_3	Co	MnO	W
16.88	37.73	15.89	0.80	1.65	1.45	1.38	0.04	-	38.72
Composition of the calcined materials (%)									
Fe_{total}	SiO_2	MgO	Al_2O_3	Ni	CaO	Cr_2O_3	Co	MnO	W
21.13	45.88	11.12	4.14	1.133	1.99	2.12	0.05	-	1.31

Table 2. Chemical analysis of auxiliary substances

Composition of Kosovo's lignite (%)								
A	Ma	Md	Koks	C_{fix}	S	S_{in}	S_{org}	W
14.59	22.42	40.76	32.93	18.34	1.03	0.66	0.37	38.72
Composition of stone coal (%)								
A	Ma	Md	Koks	C_{fix}	S	S_{in}	S_{org}	W
4.23	34.85	71.87	41.25	37.02	sign	sign	sign	23.90

A-ash,Md-burning substance, Ma-volatile matter

According to the formula:

$$w = \frac{m_1 - m_2}{m_1} \times 100 \qquad \text{Ek. (1)}$$

Where: m1- mass of wet ore

m^2-mass of dry ore

Results and Discussion

The simulation of the four charges in the laboratory rotary kiln "Linder".We have sent the prepared samples (loads), for experiments, to the laboratory of FeNi in Kavadarc. The previously mentioned laboratory has been used to determine the composition of the four charges (Table 3). Each of the charges had an amount of humidity (since the Foundry does not provide complete drying of the ore and the auxiliary substance). The first slag contains 6% humidity, the second 2%, the third 2.6%, and the fourth 2.2%. The percentage of humidity has been proven through laboratory experiments to be one of the factors that impact the increase of the pre-reduction scale in the foundry.

Table 3. Composition of fourcharges

Composition of charge								
Charge**(%)**	Fe_{tota}	Ni	Co	Cr	CaO	MgO	SiO_2	Fe_2O_3
I	18.89	1.26	0.046	1.29	1.09	13.86	47.26	25.61
II	19.71	1.28	0.047	1.26	1.49	13.69	46.18	42.84
III	20.52	1.30	0.047	1.23	1.41	13.86	40.53	36.30
IV	17.16	1.40	0.047	1.00	3.11	13.56	41.38	40.58

Table 4 Amount of samples, auxiliary substances, temperature and time of stay during simulations

Amount of charged , temperature, time of stay in the kiln, auxiliary substance							
charge:	tem.(ºC)	Time(h)	Amt. of samples(gr)	Kosovo's lignite(%) gr)		Indonesia's stone coal(%)(gr)	
I	800	3	490	6	29.4	2	9.8
II	900	3	490	6	29.4	2	9.8
III	800	3	490	9	44.1	3	14.7
IV	900	3	490	9	44.1	3	14.7

Characteristics of the rotary kiln "Linder"

- Kiln capacity: 500(gr) ore
- 17% auxiliary substance
- Temperature can increase by 14C in 1 min
- Temperature goes to 1000^0C

Figure 3. Laboratory rotary kiln "Linder"

Figure 4. Internal view of the laboratory rotary kiln "Linder"

Table 5. Composition of the calcined material for the four experiments, the pre-reduction scale, and their weight

	Fe_{total}(%)	Ni(%)	Co(%)	Cr_2O_3(%)	CaO	MgO	SiO_2	FeO	Fe_{met}	C_{fix}	Ri	Weight
I	22.42	1.26	0.052	2.20	1.20	14.92	45.10	19.49	3.73	1.11	68	445.8
II	23.15	1.29	0.050	1.66	3.39	14.83	48.10	22.79	3.32	2	76.55	464.2
III	20.59	1.46	0.051	2.10	1.51	14.92	49.41	19.58	5.67	2	77.05	449.9
IV	23.42	1.52	0.052	1.99	1.70	15.29	51.99	22.59	5.72	1.62	75.0	449.2

Composition of the calcined material for the four experiments, the pre-reduction scale, and their weight

From the obtained results we have achieved a high scale of ore pre-reduction in the laboratory kiln. The pre-reduction scale of the nickel ore is determined according to the formula used to determine the pre-reduction scale in the Foundry:

$$R_i = \frac{\%FeO}{\%Fe_{tot}} \times \frac{P_m Fe}{P_m FeO} \times 100 \qquad \textbf{Ek.(2)}$$

Where: Pm –molecular mass of FeO and Fe

First example:

$$R_i = \frac{\%FeO}{\%Fe_{tot}} \times \frac{P_m Fe}{P_m FeO} \times 100 = \frac{19.49}{22.42} \times \frac{55}{71} \times 100 = 68$$

The following is a graphical presentation of the pre-reduction scale of the four experiments. From the graphical presentations we notice that in comparison to the other experiments, during the second experiment (second charge 900C), there is an increase in the pre-reduction scale to the electrical energy needed in the process of obtaining the calcined ore.

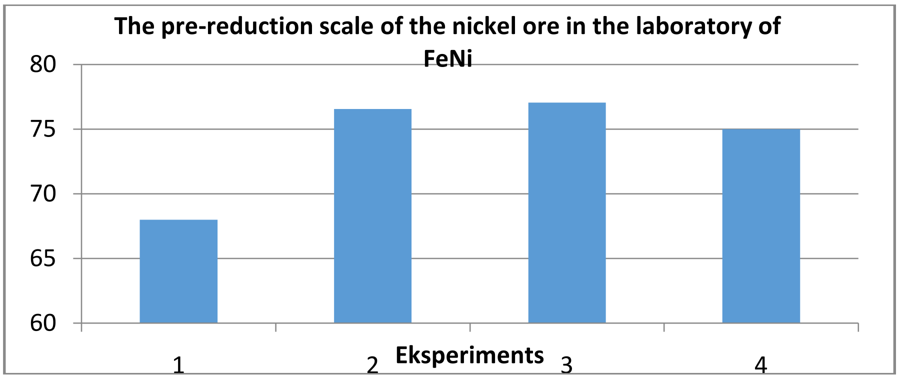

Figure 5.Graphical presentation of the experimental determination of the pre-reduction scale (Ri)

We have analyzed the pre-reduction scale of the iron-nickel ore in the industrial way through the years 2007-2014

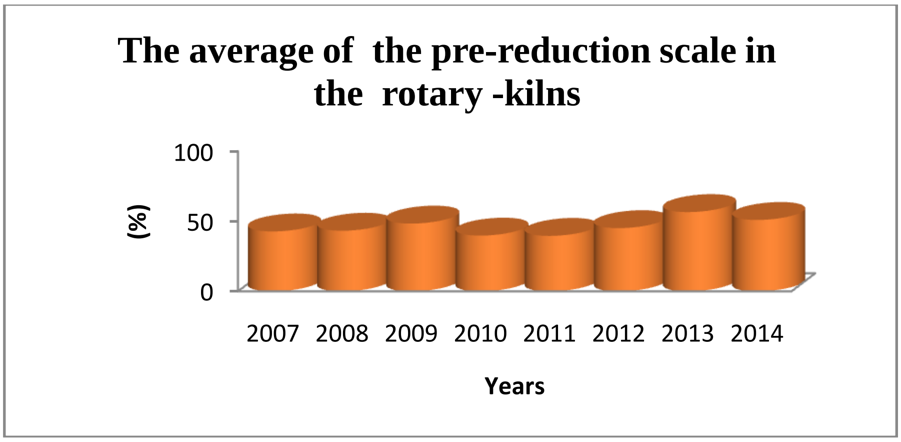

Figure 6. Graphical presentation of the pre-reduction scale of the iron-nickel ore

Conclusion

Based on the experimental results conducted in the laboratory of FeNiKavadarc, we can conclude the following: We have conducted four experiments. The first charge weighed 490 (gr); in the mixture we have added the following auxiliary substances, 29.4grKosovo's lignite and 9.8% Indonesian stone coal. The experiments have been conducted in two temperatures: 800C and 900C.Third and fourth charges have weighed 490gr. Composition of auxiliary substance: 44.1(gr) Kosovo's lignite and 14.7 Indonesian stone coal. The experiments have been conducted in temperatures of 800C and 900C.Crumbling of ore has been 5mm, whereas that of lignite has been from 1mm to 3mm.During the experiments we have achieved a satisfactory pre-reduction scale: turning of 60%-80% of Fe_2O_3 to FeO_2 and $Fe_{metal.}$ In the case of our experiments the initial losses are minimal compared to the industrial cases of ore in relation to the amount of calcined material; in the first case we have a loss of 9% in relation to the amount of ore entering the process and the amount of calcined material. The second experiment has a loss of 5.2%. The losses in the third and fourth experiments are 8.1% and 8.3%, respectively. In industrial cases the ratio ore - calcined material was 29.65% during 2010, whereas the ratio in 2011 indicates 30% less calcined material than the amount of ore.We have decreased the ore humidity in the laboratory plant. Before starting the experiments we have determined the humidity in the laboratory of FeNi in Kavadarc, and we have determined these humidity percentages according to the charge:

First charge contains 6% humidity. Second, third, and fourth charges contain 2%, 2.6%, 2.2% humidity, respectively. As confirmed by laboratory experiments; the percentage of humidity is one of the factors impacting the increase in the pre-reduction scale in the Plant. The ore pre-reduction scale has been satisfactory, starting from: 67.60%; 76.55%; 74.24%, 75.09% which compared to the industrial cases is approximately 40% higher. Another conducted advantage is the removal of humidity, which in industrial cases averages around 3% in years. From the experimental cases we have confirmed that the mixture of ore and their ratio during the mixture are among the most important factors for the realization of the pre-reduction scale. From the obtained results we have determined the factors that impact the increase of the pre-reduction scale of the nickel ore:

Crumbling 5mm of ore, mixture of ore, sizing of the auxiliary substance 1-3(mm),removal of humidity, elimination of adhesion, lack of dust, elimination of adhesion of the calcined material to the walls of the kiln. In case we increase the amount of dry ore, then apart from having changes in the technological process and an increase of the pre-reduction scale, we will also experience economic gains, because the duel(heavy oil) used to dry the ore will cost less compared to the electrical energy needed in the process of acquiring the calcined matter.

Recommendations

The experimental results lead to:

1. Ore mixtures to be as good as possible
2. Crumbling of ore and auxiliary substances should be in a certain size, according to techical-technological conditions
3. Removal of humidity
4. The mixture of the quantities of ore with higher composition of humidity should be entered in the dryer.

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