Desulfurization in the Electro-Arc Furnace, Opportunity to Increase the Fe-Ni in Drenas

Bajraktari-Gashi, Zarife; Ibrahimi, Izet*[+]

University "Isa Boletin" of Mitrovica, Faculty of Geoscience, Department Materials of Metallurgy,
40.000Mitrovica, REPUBLIC OF KOSOVO

ABSTRACT: *Ferronickel production from electric furnaces with increased concentrations of sulfur (S) and silicon (Si) and low concentration of carbon (C), has resulted in a relatively low Fe-Ni casting temperature and conditions, which have reduced the chances of desulfurization of metal outside the furnace as well as reduced the Ni/Fe-Ni utilization coefficient. Thus, although less than 80% of sulfur is separated, the desulfurization process has resulted in a long stay of the metal in the converter with increased consumption of energy sources, high consumption of refractory materials, increased metal losses with scrap, and low utilization of production capacities. De-sulfuring and heating of metal in the electro-reduction furnace would allow better temperature control, injection of the lime combination with calcium carbonate, and the possibility of de-sulfuring grime removal. A shorter time of effective distention and standing of the metal in the converter will increase the resistance of fire-proof material by up to 200%, compared with projected parameters, and 240% compared with actual parameters, in addition, it will decrease oxygen expenses by up to 50% and amalgamation for more than 70%. The total refinement cycle, including the time in the electro-reduction stove in the boiler, will take approximately 167min, the effective distention time in the converter will be approximately 36 min, whereas the working coefficient of Ni will reach up to 0.9. Evaluation of operating conditions and parameters, as well as the composition of process products, through quantitative and qualitative methods and quality control through XRD analysis during the study has proven that with partial modifications of the refining process, the application of desulfurization in the electro-arc furnace would result in reducing normative resource costs, improving the metal utilization coefficient, reducing production costs, increasing the degree of safety and process control, and increasing the utilization rate of production capacities in converters and in the ferronickel plant in Drenas.*

KEYWORDS: *Ferronickel; Effectiveness; Cost; Electric arc furnace; Desulfurization.*

INTRODUCTION

Ferronickel production during electro-reducing smelting of ores is subjected to a process with high temperatures, metal with high concentration of Si and S and slag with high degree of acidity. Thus, the enrichment, especially desulfurization of ferronickel in the Foundry of "Ferronickel" in Drenas is associated with difficulties such as: long stay time of the metal in the converter, insufficient safety and efficiency of parameters and equipment,

high consumption of refractory materials and other resources, low level of utilization of production capacities and high production cost of Fe-Ni.

Sulfur in ferronickel is mainly found in the form of FeS, this chemical mixture has a melting point of 1194℃, in which S has a tendency to digest large amounts of liquid iron [1]. According to experimental research conducted in the refining department, as well as GIBSS energy calculations, it is proven that the high solubility of [S] in [Fe], as a result of which the [FeS] molecule is formed, is followed by high effects of energy, and with that the activity of sulfur in liquid iron depends on the concentration of [S], [Si], [C] and other participating elements in Fe-Ni. Therefore, the chemical composition of Fe-Ni of the electric furnace, the quality of the slag (CaO / SiO$_2$ ratio), the oxidizing ability of smelting (metal and slag), the optimal basicity, the sulfide capacity, the fluidity, and the surface pressure among others, are determinants of the stability of the bond between sulfur and liquid iron, therefore determining the sulfur separation coefficient. In this case, we have determined the desulfurization efficiency using the pace of separation of sulfur ions at the boundary of the metal-slag phases, their transfer to the depth of the slag layers as well as by the activity of oxygen in the metal in the component of the gaseous phase, respectively.

According to the desulfurization in the electric arc furnace with acidic coating proposed in this study, all amounts of Si, C and P concentrated in the ferronickel of the electric furnace, are oxidized in the converter.

This is considered as the first stage of the refining process. After that, the second stage of the process begins, during which the metal, deoxidized with aluminum, flows into the electric arc furnace and is therefore heated to reach the proper temperature for the development of desulfurization. Theoretically, until the Si burns below 1.5%, it is unlikely to begin the desulfurization phase. Therefore, with the fall of Si below these values and the addition of Al, the desulfurization and phosphorus separation reactions will intensify. Both reactions are expected to be performed at the same time and this lasts until their level reaches the appropriate limits, which for Fe-Ni is manifested at a value below 0.02% [2]. As a reagent of basic origin, we have used CaCO$_3$, which requires a very high consumption of Al. However, judging from the theoretical aspects of desulfurization in the basic

environment, replacing CaCO$_3$ with CaO powder and adding 10-12% CaF$_2$, would have very high effects. The main purpose of the study is to restore desulfurization outside the furnace in a very advanced variant. Correction and restoration of this intermediate stage of the refining process, in addition to improving the desulfurization efficiency, would simultaneously result in rational use of resources and energy, reduction of production costs, and optimization of the production process in general.

EXPERIMENTAL SECTION

This study is based on XRD examinations and chemical analysis of Fe-Ni, (Fe-Ni of FE and LD converter) and slag, during all stages of the refining process including the composition of the metal, the granulometric and chemical composition of the desulfurization reagents, composition and volume slag and gases and other products of this intermediate phase, temperature and other parameters of the refining process. From the resultant values, we have determined the amount of reagents, the temperature of the process stages, the degree of oxidation of Si, C, P, remaining from the first stage, as well as the sulfur separation coefficient along the second stage, (desulfurization efficiency in electro arc furnaces with acid coating).

Sulphur separation coefficient, in addition to being a function of the chemical composition of the metal, it is first of all considered as the main indicator of the performance of the refining process. The values of this coefficient determine the staying time of the metal in the converter, the consumption of refractory materials, the use of capacities in the converters department and generally in the Ferronickel Foundry in Drenas. This study program followed a research diagram, as shown in (Fig. 1).

For the purposes of this study, the ferronickel production practices at PT Inco (Indonesia), Cerro Matoso (Colombia), and SNNC (South Korea) have been used. According to the statistical and comparative methods, other indicators of desulfurization outside the furnace and the refining process in the converter are also defined.

Experimental research of desulphurization crude ferronickel

In the "Ferronickel" Foundry in Drenas, crude ferronickel of the electric furnace is characterized by an average Ni content of about 15%, while the Fe-Ni melting

Table 1: Average chemical composition of crude ferronickel (EF Fe-Ni).

As	Fe	Si	Cr	C	P	S	Ni	Co	Cu
0.03	72.5-84	2.7-4.0	0.25-0.76	0.3-0.7	0.07-0.2	1.22-2.86	11.22-2.86	0.5-0.74	0.03-0.05

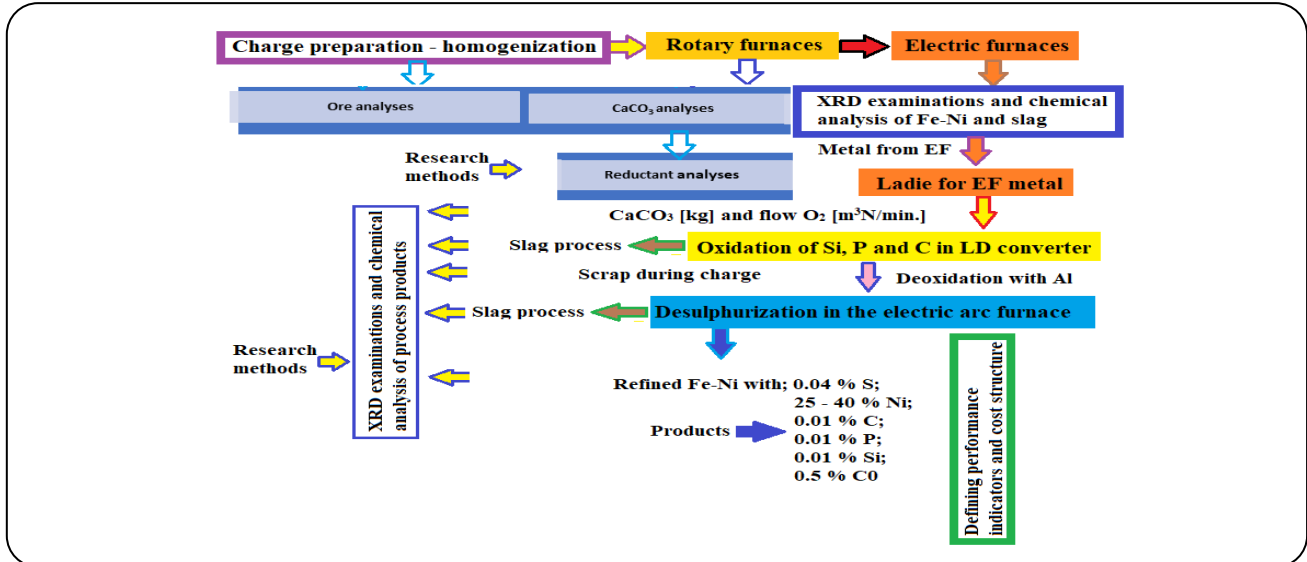*Fig. 1: Flowchart for the research methodology.*

has low content of C, ([C] <0.3%), high content Si, (2% <[Si] <4%) and low content of Cr, ([Cr] <0.4%). A noticeable characteristic is that sulfur has an high affinity to be dissolved in liquid iron. In the gross ferronickel (EF Fe-Ni), sulfur is mostly present in the form of FeS, which is due to the fact that iron is a major melting component of ferronickel [1]. In this case, the disadvantage of the ferronickel production process, and especially of the refining process is the high concentration of sulfur in the form of FeS in Fe-Ni. The binding of such a molecule required large amounts of baking soda for desulfurization outside the furnace and a long blowing time with oxygen during its refinement in the converter. Sulfur and phosphorus in molten Fe-Ni pass through the ore, lignite, fuel oil, or petroleum coke. In cost-effective metallurgical processes, sulfur, which is organically bound to the charge components is expected to pass with process gases. Theoretically, in the electric furnace 50% of S should be separated, where a part passes with gases and the other part with slag].

However, in cases where the process is followed by poor technical-technological performance and extremely low levels of profitability, high concentrations of S (over 2%) are unaffordable. According to the current parameters in the "Ferronickel" Foundry in Drenas, there are cases when the sulfur content is above 2% (Table 1.).

The average sulfur content in crude Fe-Ni is 2.04%, respectively 20.4 [kg S / t FeNi], of which, the charge of 25 [t / FeNi] will contain 510.0 [kg] S. Following existing standards, ferronickel, which is used for the production of various steels must contain a minimum amount of sulfur below 0.04%. Thus, for such qualities of ferronickel, deeper desulfurization is required before the metal goes through the refining process in the converter.

According to the current approach, there is no desulfurization outside the furnace in the "Ferronickel" Foundry, but the whole desulfurization process is developed in the converter. Theoretically, during the oxygen-blowing process in the converter, a part of the sulfur is removed with slag and the rest with gas. However, in most cases, due to unbalanced refining conditions in the converter, the reaction of metallic sulfur with oxygen is not possible [1-2], regardless of free GIBSS energy, (Reaction (1)).

$$G^0 = 1340 + 12.8t \tag{1}$$

Thus, the process of refining the crude ferronickel, and especially sulfur separation, develops extremely slowly and is associated with a high expenditure of technological resources.

Table 2: Origin of S, Si and C in crude Fe-Ni

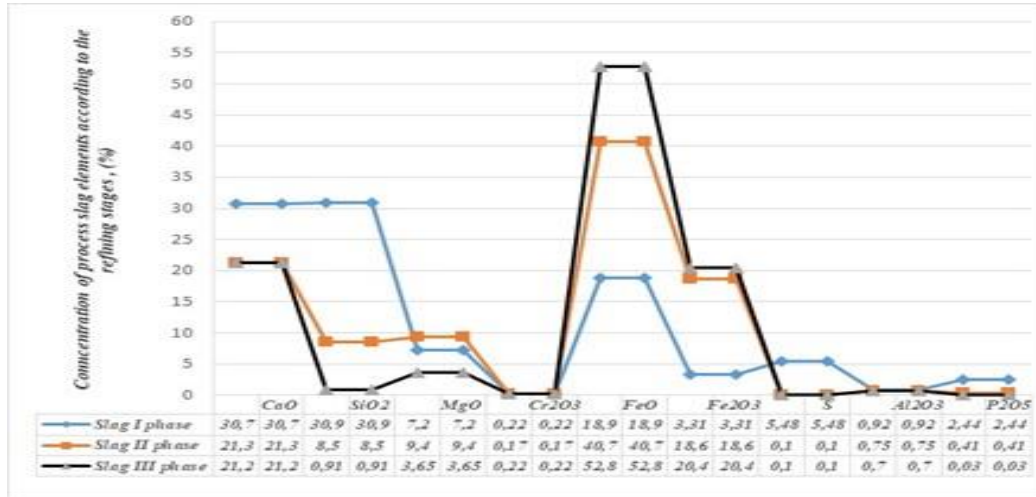|	Dried ore 57555 t		Lignite 5041t		Mazut 4661.6 t		Charge in RRK 50937t		Electrode mass 85% C 2.78kg/1000kWh	Charge in EF 50937 t		EF Metal 132.484	
	t	%	t	%	t	%	t	%	t	t	%	t	%
S	11.5	0.02	80.66	1.6	42.9	0.92	115.6	0.23	112.3	227.9	0.45	1.66	1.25
C	-	-	1217.4	24.2	3976	85.3	983	1.92	113.4	1276	2.51	0.52	0.39
SiO_2/Si	27108	47	317.6	6.3	-	-	25433	49.9	-	-	-	3.58	2.70

Fig. 2: Concentration of process slag elements according to the refining stages.

From the material balance data of the process calculated for the study time, the main sources that determine the chemical composition of Fe-Ni are shown in Table 2.

Ore is the key factor that determines the composition of the metal and the concentration of Si in the metal. The concentration of Si in Fe-Ni depends on the concentration of SiO_2 in the ore. Between the concentrations of [Si] and [C] in the molten liquid of Fe-Ni, there are connections dependent on the process temperature. The reduction of Si from SiO_2 is dependent on the acidity ratio (pH) and the process temperature. A high degree of Si reduction is achieved when the process temperature is $1600\,°C$. However, the process temperature has little effect on the oxidation degree of Si, due to the small effect of temperature on the diffusion coefficient of oxygen in the slag. Fig. 2 shows the average chemical compositions of slag according to the refining stages in the converter,

while in Table 3 the technical-technological parameters of the refining process according to the chemical composition of the slag as well as other prevailing conditions in the converters department are demonstrated.

Due to the long duration of the presence of metal and the aggressive behavior of slag, the utilization of the production capacities in the converters' department was not higher than 9000 t Ni /year, i.e. only 77.4% of the design capacity. Table 4 shows the average efficiency indicators, in the case when desulfurization was performed outside the furnace with Na_2CO_3 and according to the current approach. Currently, this intermediate phase does not exist, and all desulfurization is performed on the converter.

According to the process indicators, the desulfurization rate in the first stage for both practices was very low. Whereas in the second stage, when the composition of FeO in the slag falls below the value of 18% FeO, conditions for desulfurization are created. This is one of the reasons that make it necessary to apply desulfurization outside the furnace.

Desulfurization in the electric arc furnace with acid coating

According to the chemical composition of the crude Fe-Ni (Tab. 5), the parameters of the desulfurization phase, as well as based on other indicators of the refining process such as the application and correction of the desulfurization intermediate phase through the electric arc

Table 3: Average chemical composition of ferronickel and slag, as well current technical-technological parameters of refining process in the Foundry of "Ferronickel" in Drenas.

No. charge	No. refractory durability	Time stay in conv. [h]	duration of flowing O$_2$ [min]	Concentration of crude Fe-Ni, [%]						Concentration of slag, [%]					Scrap charge, [t]	Process temp. [0C]
				Si	Cr	C	P	S	Ni	CaO	SiO$_2$	MgO	FeO	Fe$_2$O$_3$		
C-0831	1	2.40	67	3.03 0.01 0.01	0.28 0.18 0.01	0.53 0.01 0.01	0.16 0.01 0.01	1.67 0.45 0.17	11.42 28.91 36.31	30.7 20.3 22.2	30.9 8.5 0.9	7.2 9.42 3.63	18.9 21.3 52.8	3.31 18.7 20.4	3	1360 1550 1540 1560
C-0835	4	2.13	53	3.07 0.01 0/01	0.30 0.17 0.01	0.60 0.01 0.01	0.18 0.01 0.01	1.68 0.55 0.28	11.48 26.7 35.4	30.2 28.7 20.9	30.8 9.7 0.8	10.4 8.4 3.5	17.9 20.39 54.7	3.2 18.6 21.7	2.5	1370 1540 1550 1570
C-0839	9	2.20	62	2.61 0.01 0.01	0.27 0.16 0.01	0.33 0.01 0.01	0.16 0.01 0.01	1.13 0.41 0.14	19.37 28.73 42.43	30.1 22.2 23.0	32.1 8.3 0.8	6.72 8.70 0.85	17.6 39.7 51.4	3.30 18.3 19.4	2.5	1370 1520 1530 1560
C-0841	11	2.36	66	2.49 0.01 0.01 0.01	0.31 0.25 0.01 0.01	0.36 0.01 0.01 0.01	0.17 0.01 0.01 0.01	2.86 1.83 0.88 0.78 0.34	18.94 24.41 28.7 46.19	28.4 29. 8 20.3 19.5	32.4 29.8 8.22 0.78	10.7 6.78 8.65 0.82	16.8 18.9 41.7 53.8	3.23 3.28 19.7 21.0	2	1380 1560 1530 1550

Table 4: Comparison of average consumption of technological resources and indicators of efficiency of the refining process, when desulfurization was applied outside the furnace with Na$_2$CO$_3$ (charge no. 1719 -1726) and according to current conditions (charge no. C-0831-0841).

No. charge	Consumption of technological resusr.			Crude Fe-Ni and refined Fe-Ni				Charge extension time [h]	Effective oxygen blowing [min]	Year when was developed the refining process.	Crude ferronickel analysis			
	CaCO$_3$ [kg]	O2 [Nm3]	Crushed Mg bricks and CaCO3 ratio. 2:1 [kg]	Fe-Ni from EF [kg]	S in refined Fe-Ni [%]	Scrap [kg]	% Ni in Fe-Ni				Si	C	S	Ni
1719	6620	1043	/	19000	0.09	3000	43.19	161	55	1997	2.65	0.32	1.24	18.53
C-0831	5380	1855	360	22000	0.40	1500	18,06	121	56	2019	3.03	0.53	1.67	11.42
1722	8550	1214	/	18560	0.10	1500	42.43	180	68	1997	2.50	0.32	1.13	19.37
C-0833	6480	2101	670	19800	0.44	4500	17.69	111	58	2019	2.98	0.60	1.67	11.23
1724	7650	1169	/	20600	0.08	2600	45.88	153	63	1997	2.69	0.33	1.23	18.32
C-0835	6940	1743	840	21000	0.42	1500	16.72	73	53	2019	3.07	0.60	1.68	11.48
1726	9010	1414	/	18960	0.09	2500	45.95	180	50	1997	2.05	0.32	1.38	18.12
C-0841	5740	1942	600	23000	0.44	2500	17.61	112	55	2019	2.86	0.60	1.62	11.22

Table 5: Average chemical composition of some of the constituent elements of the ferronickel in the electric furnace, and the concentration of S in the refined ferronickel for the study period (10.12.2019 - 10.01.2020).

S	C	Si	Ni	Fe	% e S në Fe-Ni raf.
1.45 - 2.86	0.57- 0.71	2.97 - 3.32	10.5 - 11.8	70.3 - 80.7	0.28 - 0.45

furnace - with acid coating, would be one of the convenient options for improving the technical performance, optimizing the production process, reducing production costs, improving the safety and increasing the utilization coefficient of the metal as well as increasing the utilization of the production capacities in the "Ferronikeli" Foundry in Drenas.

During desulfurization in the electro-arc furnace with acid coating, all Si, C and P concentrated in the crude Fe-Ni, are oxidized in the converter from the first stage of the process. The metal is then deoxidized with Al and heated in the electro-arc furnace to reach the desired metal temperature. The reactions of desulfurization are expected to be carried out at the same time, so that the level of impurities falls to the desired limits [2].

The second phase is characterized by the intermediate phase of desulfurization in the electro-arc furnace of crude Fe-Ni with the presence of Al as a control element of oxygen activity, and in which metal (Fe-Ni) does not contain Si and C.

As a reagent of basic origin desulfurizer can be used $CaCO_3$, which requires a fairly large consumption of Al, as deoxidizing elements. Moreover, replacing $CaCO_3$ with the powder CaO and 10-12% CaF_2, ensure rational reagents, according to theoretical predictions [2, 3].

The consumption of CaO powder is slightly higher than the consumption of $CaCO_3$. Following this practice, during the desulfurization process, heating of the molten metal is not envisioned before placing it in the arc furnace. However, due to the decrease of temperature between the stages of the process, it is necessary to heat the metal with the electric arc. Optimal operating conditions are characterized by temperatures of values slightly above the melting point of the crude ferronickel, where in these conditions we notice an increases in the rate of desulfurization [2,3,4,8].

The injection of a mixture of 40% CaO, 40% FeO and 20% CaF_2 gives satisfactory effects regarding the rate of dephosphorylation of the crude ferronickel [2,3].

Table 6 shows the technical-technological parameters and the cost structure for the desulfurization of the ferronickel in the arc electric furnace with acidic coating / acidic environment.

In these desulfurization practices, electromagnetic mixing is necessary as it increases the efficiency of the intermediate phase. This also speeds up the reactions and facilitates the process of melting the scrap in the furnace. Smelting and recovery of scrap would increase the metal utilization coefficient and reduce production costs.

RESULTS AND DISCUSSION

If the former practice of desulfurization outside the furnace with molten Na_2CO_3 would resume the former function, we would reach a maximum desulfurization coefficient of 2.58 with a maximum desulfurization rate of up to 40% [3, 4]. Sulfur separation between metal and slag is expressed through the sulfur removal efficiency coefficient (as in relation 2);

$$L_S = \frac{(\%s)}{[\%s]} = K_0 \frac{a_{0^{2-}} \cdot f_{[s]}}{a_{[0]} \cdot f_{s^{2-}}} \qquad (2)$$

The main indicators of performance and effectiveness from the application of this intermediate phase would be:

• Desulfurization and heating of the metal in the electro-arc furnace, enabling high control of temperature, injection of CaO powder mixture, faster development of chemical reactions and efficient removal of slag.

• Reduction of over 50% of the intensive with oxygen blowing time and high reduction of staying time of metal in the converters, thus increasing durability of refractory coating of up to 200% compared to the design parameters and 240% compared to the current operative parameters.

• Reduction of oxygen costs by 50% and $CaCO_3$ or CaO for more than 70% compared to current parameters, and at the same time it will lead to a reduction in the amount of slag and losses of Ni with slag.

• During this practice of desulfurization, the total stay time of the metal in the converter is up to 15 min, while that of desulfurization in the electro-arc furnace including both intermediate phases is on average up to 24 min, whereas the Ni utilization coefficient will reach up to 0.9;

Table 6: Technical-technological indicators with the cost structure of desulfurization of the intermediate phase of the crude ferronickel in arc electric furnace with acidic coating / acidic environment, by injected of powder reagent.

Process phase	Conc. Si dhe S [%]	Phase temp.[0C]	Phase time [min]	Cost. [$/t]	Other
Casting (Fe-Ni from EF)	2.8 Si 1.28 S	1350	25		
Transport.		1340	5		
Oxidation of Si, C in conver.	0.05 Si 0.05 C	1650	30	15	1500 kg $CaCO_3$ 10 kg m.z./t 5 t scrap
Removal of slag and addition of CaO		1490	10	6	500 kg CaO
Addition of Al	0.4 Al	1625	10	12.5	175 kg Al
Temperature measurement	-	1625	10		
Desulphur. by injected (first degree)	0.1 S	1520	16	10	800 kg CaO
Removal of slag and addition of CaO		1510	10	5	400 kg CaO
Heating in the electric arc furnace		1620	30	55 x	1200 kwh energ.
Desulphur. by injected (second degree)	0.04 S	1570	8	5	400 kg CaO
Removal of slag and addition of CaO		1560	10	5	400 kg CaO
Dephosfor. by injected	0.04 P	1480	4	6	80 kg(40% CaO 40% FeO 20% Ca 20% CaF_2 Consump. of spears
Removal of slag		1470	10	31	800 kwh
Total			178	150.5	

According to industrial reviews, the previous practice of desulfurization compared to the current practice (development of desulfurization only in the converter) has resulted in high deviation of performance indicators and sulfur separation coefficient between charge 1722 and C-0853-C-0841 (Tab. 7 and 8).

Fig. 3 compares the degree of sulfur separation between metal and slag expressed through the coefficient of the desulfurization efficiency, for the three following desulfurization practices; desulfurization in the converter, desulfurization with Na_2CO_3 and desulfurization in electric arc furnace with an acidic environment.

From practical data as well as from the literature [5, 8,14,13], it is understood that the maximum desulfurization rate according to practice with Na_2O_3, for the conditions of an optimal metal melting composition and a good temperature control of the intermediate phase, was not higher than 25%. Whereas, in the practice of desulfurization with electro-arc furnace with acid coating and powder reagent, (according to theoretical parameters), desulfurization reaches values of over 50% only in its second degree.

From the results of the chemical composition analysis of metal and slag regarding the process phases, it is evident that the main determining factors for the erasure of the fireproof wall, the efficiency of desulfurization outside of the furnace, enrichment of the crude ferronickel in converters as well as other consumption parameters are:

• Crude ferronickel, with a high concentration of S (1-1.6%), Si(1.5-3%), and a low concentration C of values under 0.5%,

• Low pouring temperatures, creating losses of base metal with "cold metal" in the boiler for receiving crude ferronickel and in the pouring channels of the electric furnace

• Slags of high FeO composition, from 18-62%, have resulted in double negative effects such as:

a) reduction of desulfuring scale and

b) the aggressive behavior of these slags towards the fireproof gear of the convertor.

• The scale of desulfurization of crude ferronickel outside of the furnace

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Table 7: Comparison of performance indicators and effectiveness for three practices (desulfurization in the converter, desulfurization with Na2CO3 and desulfurization in the electric arc furnace).

No. charge	S of rafined Fe-Ni, (%)	Desulphurization rate, (%)	The effective separation coefficient of S
C - 0841	0.37	87.1	8.71
1722	0.10	94.0	9.49
Desulphurization in AEF (theorik.)	0.004	96.9	9.69

Table 8: Average chemical compositions of ferronickel, slag, and other technical-technological parameters of the refining process according to the current practice (charge no. C-0835-C-0841) and the practice of desulfurization with Na2CO3 (charge no.1722) in the Foundry of "Ferronickel" in Drenas

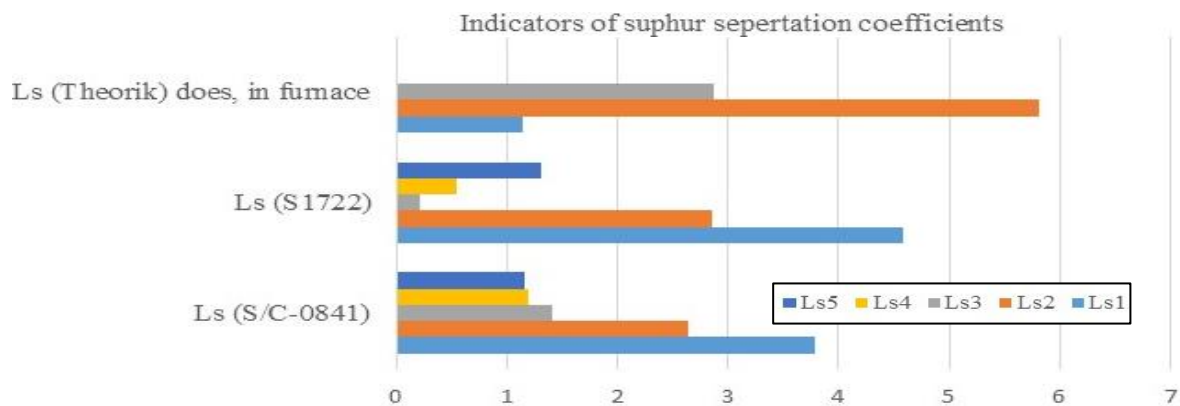| No. charge	No. refractory durability	Time stay in conv. [h]	Dration of flowing O2 [min]	Concentration of crude Fe-Ni, [%]						Concentration of slag, [%]					Scrap charge, [t]	Process temp. [0C]
				Si	Cr	C	P	S	Ni	CaO	SiO2	MgO	FeO	Fe$_2$O$_3$		
1722	1	2.40	67	3.03 0.01 0.01	0.28 0.18 0.01	0.53 0.01 0.01	0.16 0.01 0.01	1.13 0.58 0.45 0.17 0.07	11.42 28.91 36.31	30.7 20.3 22.2	30.9 8.5 0.9	7.2 9.42 3.63	18.9 21.3 52.8	3.31 18.7 20.4	3	1360 1550 1540 1560 1580
C-0835	4	2,13	53	3.07 0.01 0/01	0.30 0.17 0.01	0.60 0.01 0.01	0.18 0.01 0.01	1.68 0.55 0.28	11.48 26.7 35.4	30.2 28.7 20.9	30.8 9.7 0.8	10.4 8.4 3.5	17.9 20.39 54.7	3.2 18.6 21.7	2.5	1370 1540 1550 1570
C-0839	9	2.20	62	2.61 0.01 0.01	0.27 0.16 0.01	0.33 0.01 0.01	0.16 0.01 0.01	1.13 0.41 0.14	19.37 28.73 42.43	30.1 22.2 23.0	32.1 8.3 0.8	6.72 8.70 0.85	17.6 39.7 51.4	3.30 18.3 19.4	2.5	1370 1520 1530 1560
C-0841	11	2.36	66	2.49 0.01 0.01 0.01	0.31 0.25 0.01 0.01	0.36 0.01 0.01 0.01	0.17 0.01 0.01 0.01	2.86 1.83 0.88 0.78 0.34	18.94 24.41 28.7 46.19	28.4 29. 8 20.3 19.5	32.4 29.8 8.22 0.78	10.7 6.78 8.65 0.82	16.8 18.9 41.7 53.8	3.23 3.28 19.7 21.0	2	1380 1560 1530 1550

Fig. 3: Avoidance of sulfur separation coefficients for 1721 and C-0835 charges and theoretical separation coefficient according to desulfurization practice in acid arc furnaces with acid coating.

Table 9: Chemical composition of ferronickel and slag, other technical-technological refinement parameters analyzed for the purpose of a campaign regarding fireproof convertor gear executed in the "Ferronikeli" Foundry in Drenas.

Charge number	Stability number	Charge duration [h]	Oxygen blowing duration [min]	Ferronickel composition [%]						Slag composition [%]					Dumping of scarp [t]	Process temp [°C]
				Si	Cr	C	P	S	Ni	CaO	SiO_2	MgO	FeO	Fe_2O_3		
1721	1	2.20	60	2.63 / 0.01	0.28 / 0.01	0.32 / 0.01	0.16 / 0.01	1.21 / 0.45	19.51 / 36.31	30.7 / 21.3	30.9 / 8.5	7.14 / 9.42	18.8 / 21.3	3.31 / 18.7	3	1360 / 1540
1722	2	2.40	68	2.51 / 0.01	0.27 / 0.01	0.33 / 0.01	0.16 / 0.01	1.13 / 0.14	19.37 / 42.43	31.1 / 23.0	31.1 / 0.8	6.82 / 0.85	18.7 / 51.4	3.32 / 19.4	2	1370 / 1560
1723	3	2.36	66	2.49 / 0.01	0.31 / 0.01	0.36 / 0.01	0.17 / 0.01	1.17 / 0.14	18.94 / 46.19	29.8 / 19.5	29. / 0.78	6.78 / 0.82	18.9 / 53.8	3.28 / 21.0	2	1380 / 1550
1724	4	2.33	63	2.69 / 0.01	0.29 / 0.01	0.33 / 0.01	0.16 / 0.01	1.23 / 0.16	18.32 / 45.88	32.5	32.6	8.23 / 0.98	19.8 / 54.82	3.32 / 21.48	2	1368 / 1560
1725	5	2.02	48	2.67 / 0.01	0.36 / 0.01	0.29 / 0.01	0.16 / 0.01	1.20 / 0.15	18.30 / 43.67	33.4 / 24.4	33.5 / 0.13	9.31 / 1.61	19.21 / 22.81	3.31 / 21.41	2	1370 / 1550
1726	6	3.0	60	2.05 / 0.01	0.33 / .01	0.32 / 0.01	0.15 / 0.01	1.38 / 0.15	18.12 / 45.95	-	-	-	-	-	3	1372 / 1560
1727	7	2.06	55	2.15 / 0.01	0.32 / 0.01	0.33 / 0.01	0.16 / 0.01	1.43 / 0.15	18.36 / 45.16						3	1369 / 1560
1728	8	2.02	60	2.78 / 0.01	0.27 / 0.01	0.32 / 0.01	0.16 / 0.01	1.34 / 0.12	17.65 / 44.9						3	1358 / 1480 / 1540
1729	9	2.10	58	2.03 / 0.01	0.34 / 0.01	0.34 / 0.01	0.17 / 0.01	1.32 / 0.13	17.25 / 42.65						3	1375 / 1450 / 1490
1730	10	2.35	64	2.79 / 0.01	0.29 / 0.01	0.36 / 0.01	0.15 / 0.01	1.41 / 0.13	44.23 / 17.71						2	1352 / 1470 / 1560
1731	11	2.18	56	2.76 / 0.01	0.32 / 0.01	0.35 / 0.01	0.16 / 0.01	1.47 / 0.15	17.71 / 37.56							
1732	12	2.20	53	2.88 / 0.01	0,,28 / 0,1	0.33 / 0.01	0.16 / 0.01	1.34 / 0.15	17.07 / 38.32							1356 / 1480
1733	13	2.48	60	2.83 / 0.01	0.29 / 0.01	0.34 / 0.01	0.16 / 0.01	1.41 / 0.15	17.05 / 47.24	21.8 / 20.5	9.68 / 7.89	9.13 / 3.12	20.45 / 22.62	41.77 / 60.57	3	1480 / 1580
1734	14	2.20	62	2.76 / 0.01	0.31 / 0.01	0.34 / 0.01	0.16 / 0.01	1.4 / 0.14	17.45 / 40.53	20.6 / 21.0	9.72 / 6.89	9.51 / 3.88	21.34 / 23.45	42.06 / 60.35		1460 / 1580
1735	15	2.30	59	2.76 / 0.01	0.31 / 0.01	0.33 / 0.01	0.14 / 0.01	1.36 / 0.09	16.93 / 39.13	22.7 / 20.4	9.53 / 2.53	9.97 / 4.21	21.54 / 22.83	47.05 / 59.81	1	1450 / 1560
1736	16	2.40	70	2.37 / 0.01	0.32 / 0.01	0.35 / 0.01	0.15 / 0.01	1.33 / 0.12	17.17 / 38.93	30.9 / 20.7	31.2 / 1.53	7.32 / 4.5	3.31 / 20.54	18.92 / 48.36	2	- / 1560

Table 9: Chemical composition of ferronickel and slag, other technical-technological refinement parameters analyzed for the purpose of a campaign regarding fireproof convertor gear executed in the "Ferronikeli" Foundry in Drenas

Charge number	Stability number	Charge duration [h]	Oxygen blowing duration [min]	Ferronickel composition [%]						Slag composition [%]					Dumping of scarp [t]	Process temp [°C]
				Si	Cr	C	P	S	Ni	CaO	SiO$_2$	MgO	FeO	Fe$_2$O$_3$		
1737	17	2.30	64	2.56	0.28	0.36	0.17	1.41 0.15	17.19 33.99	32.2 22.6	35.2 2.72	8.33 3.02	3.35 21.23	28.24 49.98	2	- 1560
1738	18	2.25	63	2.63	0.30	0.36	0.16	1.46 0.12	17.05 42.17						1	1430 1560
1739	19	2.15	53	2.59	0.22 0.01	0.35 0.01	0.16 0.01	1.39 0.14	16.85 43.83	32.0 22.1	29.8 0.91	5.68 5.36	21.45 63.52	3.15 21.45	1	- 1560
1740	20	2.32	62	2.48	0.28 0.01	0.34 0.01	0.16 0.01	1.34 0.15	16.81 43.83	29.7 16.6	29.7 1.23	6.65 3.52	20.24 41.73	3.56 21.45	3	- 1560
1741	21	2.29	51	2.41	0.27 0.01	0.34 0.01	0.15 0.01	1.33 0.13	17.02 45.89	30.7 16.2	31.5 2.63	5.56 5.82	21.07 42.21	3.32 22.13	3	- 1550
1742	22	2.15	68	1.98	0.28 0.01	0.35 0.01	0.16 0.01	1.38 0.14	16.87 43.82	27.3	31.6	8.02	18.45	3.31	2	- 1560
1743	23	2.00	51	2.57	0.28 0.01	0.34	0.16	1.27 0.11	16.96 37.90						2	- 1560
1744	24	2.39	68	2.39 0.01	0.3	0.33	0.16	1.28 0.12	17.26 40.60	29.3 18.2	30.4 0.91	5.95 7.54	18.98 52.04	3.33 20.25	1	- 1560
1745	25	2.00	53	2.55	0.31 0.01	0.33	0.16	1.37 0.14	16.98 37.28	30.3 19.2	31.0 0.85	7.58 5.23	18.97 50.34	3.28 20.41	2	- 1550
1746	26	2.40	54	2.69	0.33 0.01	0.37	0.16	1.38 0.10	16.34 37.28	30.3 18.1	31.3 0.8	8.85 5.56	18.81 48.75	3.01 20.45	2	- 1550

• Disproportional dynamics of the removal of silicon, chromium carbon, sulfur, and other accompanying elements from the crude ferronickel by desulfurization outside the furnace and in the convertor.

In theory, the desulfurization, dephosphorization, and enrichment of the crude ferronickel in the Foundry of "Ferronickel" in Drenas should last 40-50 minutes, while according to the test results for the loads presented in Tab. 9 with the current production regime, the process of desulfurization and refining of the crude ferronickel has completely lasted from 48-70 minutes.

Such a long time of intensive blowing with oxygen creates a high rate of production costs and at the same time has reduced the level of utilization of production capacity due to the long stay of the metal in the converter.

The dynamic of removing accompanying impurities from crude ferronickel is dependent on:

The affinity of Si concerning oxygen, based on the magnitude of ΔG, shown in reaction 2, at a temperature of 1600 and 1900°C, results in ΔG equal to 226087.2[J], respectively 157005[J].

$$[Si] + 2[O] = (SiO_2) \tag{2}$$

The formation energy of SiO$_2$ at the given temperature (1600°C-1900°C), is equal to 594944.28[J] and 538003.8 [J], which is significantly greater than ΔG for the oxides of the elements entering the ferronickel composition.

Carbon combustion begins after reaching a temperature of up to 1500 0C, only after the concentration of silicon has dropped to 0.5 or 1.5% in crude ferronickel.

The rate of chromium removal is determined primarily by the temperature of the converter slag. Its rapid oxidation occurs at temperatures higher than 1300 0C, whereas under this temperature its oxidation decreases. However, during the timeframe corresponding to the combustion of Si, the major quantities of carbon and chromium leave the process.

Most of the sulfur remains to be removed in the blowing phases when the process slag is continoulsy followed by high concentrations of FeO, significantly affecting the removal efficiency of sulfur from crude ferronickel.

CONCLUSIONS

The high concentration of S and Si, and low concentration of C in the electric ferrous metal, as well as the lack of desulfurization outside the furnace has resulted in a refining process with a long period of intense blowing with oxygen, high costs of refractory materials, high production costs and at the same time has reduced the level of utilization of production capacity due to the long stay of the metal in the converter.

Ferronickel for the production of various steels should contain no more than 0.04% S, however, the ferronickel refined in converters LD in the "Ferronikeli" Foundry in Drenas, according to current practice is of quality from 7 to 11.2 times below the required standard. Therefore, partial modifications of the refining process through the application of desulfurization in electro-arc furnace with acid coating would result in positive effects, reducing normative resource costs, improving the metal utilization coefficient, reducing production costs, increasing the degree of safety and process control, and increasing the utilization rate of production capacities in converters and in the NewCo "Ferronikeli" in Drenas.

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