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REFINING STEEL IN AN INDUCTION LADLE FURNACE

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Abstract: This paper depicts the results of experimental research concerning the synthetic cinders used in the steel industry, cinders obtained from waste powder. The widespread introduction of refining liquid steel by synthetic slag pot is conditioned by the high costs and the lack of technical alumina obtained from bauxite, a component of the synthetic slag. The possibility of improving the purity of steel through refining and with the help of synthetic slag has been analyzed: while mixing steel with slag we focused on the achievement of a contact and interaction surface 300 times larger than in the electric arc furnace, the physical–chemical .properties of slag suitable for the reduction of sulfur and oxides inclusions, to meet these conditions, knowing the physical chemical reactions, the metal–slag system is binding when the two fazes are intensely mixed. These cinders can be added in the ladle of liquid or solid steel. For the industrial experiments solid steel was the choice because the furnace for melting synthetic slag was not available on the working platform.
Keywords: wastes, synthetic slag, steel, siderurgy, refining

1. INTRODUCTION

The steel processes underlying the production of iron, ferroalloys, refineries and even casting (especially the continuous one) of the iron are happening due to the involvement of slag. Its chemical and physical characteristics must be consistent with the essence of the project and with its purpose. In the development of the iron, the slag must be in a fluid state, must have a reducing nature, and have the ability to embed larger loads of ore, tailings and some impurities. At the development of steel it must be oxidant to ensure the refining of the metal bath or reducing the deoxidation and desulphurization character to facilitate the removal of oxygen and sulfur in steel. At the electric melting of steel under slag, the latter must have reducing character, must be fluid and with retention and high capacity of retaining the impurities (sulfur and nonmetallic inclusions), and at the continuous casting of steel it must also have reducing character, be fluid to lubricate the walls crystallizer and to have protective action against gas ingress into steel.

Ordinary steel developed in furnaces without special technological measures for quality improvement, contains waste, excessive quantities of impurities, especially non–metallic inclusions of oxides and sulfides. With the increasing content of such inclusions, and worsen of heterogeneity the mechanical and technological characteristics of steel increase.

The refining of liquid steel with clay powder or with various mixtures of synthetic slag has increased based on shift unwanted impurities (sulfur, suspended minerals, oxygen) of liquid steel in the slag, mainly by diffusion, or partly by involving the suspension of clay particles in the synthetic pond thus being subject to the treatment inside the bath of steel.

The summary of the process using synthetic slag is to achieve a lasting contact on a greater surface between the processed metal and slag, whose composition is chosen so as to provide an advanced desulphurization and deoxidation of the metal.

In the processing of steel with synthetic slag, when, after shooting at high altitude, the steel crosses the slag as a multitude of drops, the interphase surface area S takes values thousands of times higher than in the case of the deoxidation of the metallic bath with white or Carbide slag, inside the electric arc furnace.

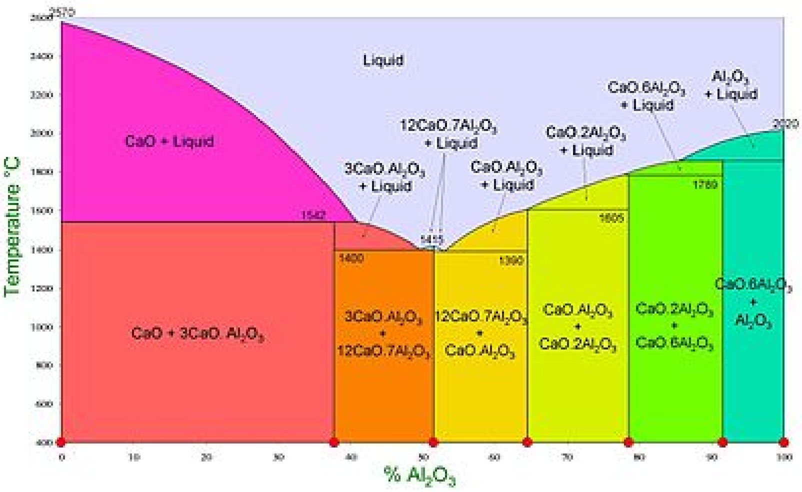

Figure 1. Binary equilibrium diagram $CaO–Al_2O_3$

As well as the deoxidation effect, synthetic slag due to their basic character and high fluidity, to their high capacity and increased dispersion surface; provide very favorable conditions for desulphurization. In the case of treatment with $CaO–Al_2O_3$ slag system L_S = (S)/[S] = 100...200 [4] reports were obtained.

Synthetic slag used in the treatment of steel slag systems $CaO–Al_2O_3$, $CaO–Al_2O_3$ –CaF_2, $CaO–TiO_2$, $CaO–CaF_2$ are presented in patented works, the best results being obtained with soda lime–alumina slag, whose equilibrium diagram is shown in Figure 1. [1] [2], [3], [5]

2. EXPERIMENTAL

The secondary treatment of steel with the synthetic slag takes place in the pouring ladle. With increasing of the height of fall of the jet, the medium–range of emulsified slag particles in steel drop. Contact area increases significantly up to a certain amount of drop height of the jet and then remains practically constant [4]. These data have great practical significance, since the tendency to increase the effectiveness of steel refining, favors an excessive increase in drop height of the jet, because over a certain amount of it takes place in a slag crusher so that small particles remain in steel slag, leading to the formation of slag inclusions. Typically, the drop height is 5–7 m.

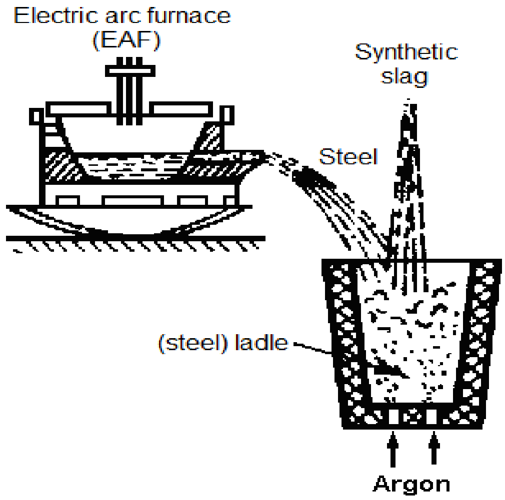

Figure 2. The secondary treatment of steel with the synthetic slag

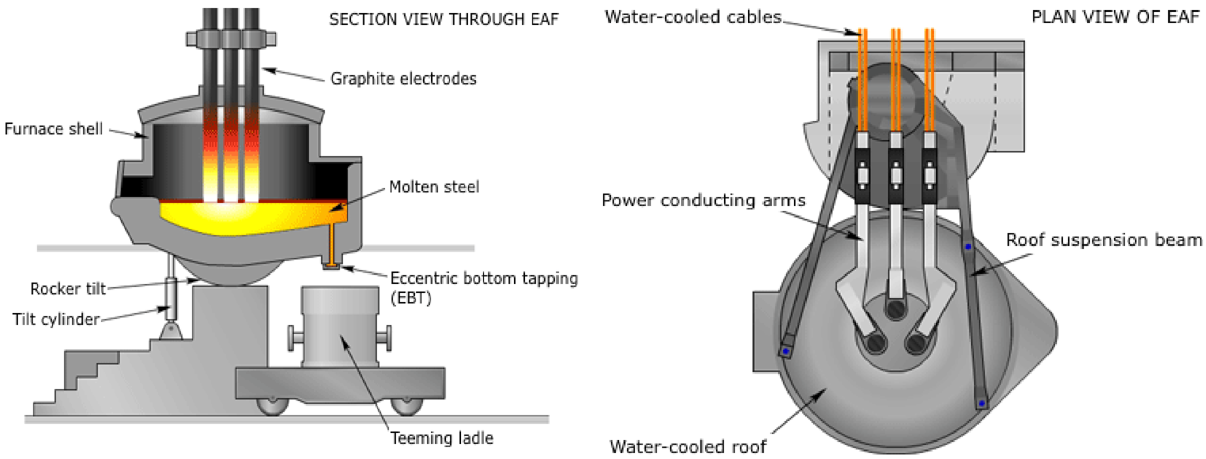

Figure 3. Steel electric melting furnace (type EBT) – Section and plain view [source: steeluniversity.org]

Experiments in Electric Steelwork 2 were conducted on 16 batches of steel (four batches / recipe) developed in electric arc furnace of 100 tons – UHP, steel pipe for production (Fig. 3). In this case given the fact that the removal of steel from the furnace is made in one pot, a comparison was made with other batches of the same brand of steel produced under similar conditions.

To obtain reducing slag, 30min before removal from the oven, a mix in an amount of from 4 to 14,5 kg / t steel was placed on the bottom of the ladle for pouring steel, consisting of: lime (68 – 75% by weight of the mixture and grain in 40 mm), calcium fluoride (in amounts of 14–17% and grain in 35 mm) and alumina slag (11–15% with a particle sized less than 25mm). Also, in this case (Table 1), to offset the heat loss resulting from melting the mixture, the exhaust temperature was 20 – 40 ^{0}C higher than normal. The chemical composition of formed synthetic slag is shown in Table 2.

Table 1. The chemical composition of the materials used

Elements	Chemical composition, [%]							
	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Al	CaF_2	H_2O
Lime	92.5	2.40	3.10	0.2	0.8	–	–	–
Slag	9.95	4.04	2.75	51.88	3.06	10.2	–	1.20
Calcium fluoride	4.30	1.20	0.45	0.65	0.90	–	90.82	–

Table 2. Chemical composition of synthetic slag

Chemical composition of formed slag: lime 70%; 20% alumina slag and 10% calcium fluorine	Chemical composition, [%]						
	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	Al	CaF_2
	66.81	2.53	2.72	10.56	1.28	2.07	9.11

In all variants steel samples as well as slag samples were tested from the exhaust stream and ladle at 15min after its filling and, immediately after filling the casting ladle. Based on evidence analyzed, it was determined the chemical composition of steel and slag, and consequently, the way to calculate the degree of deoxidation and desulphurization (Table 3).

Table 3. The yield desulphurisation

Crt. No.	Sulfur content, [%]			Degree of desulphurization [%]	
	S_{topire}	$S_{oală}$	S_{final}	$\eta_{S\,zgs}$	$\eta_{S\,total}$
1.	0.044	0.027	0.016	40.74	63.64
2.	0.043	0.023	0.014	42.74	64.66
3.	0.040	0.024	0.014	50.00	70.00
4.	0.046	0.023	0.014	53.00	66.01
5.	0.050	0.026	0.014	46.15	72.00
6.	0.052	0.026	0.014	46.15	74.00
7.	0.054	0.026	0.014	46.15	74.07
8.	0.045	0.028	0.016	42.86	64.44
9.	0.054	0.025	0.012	52.00	77.78
10.	0.050	0.022	0.014	36.32	72.02
11.	0.050	0.024	0.014	36.36	72.00
12	0.050	0.026	0.012	34.32	70.01
13	0.050	0.030	0.013	56.67	74.00
14.	0.048	0.028	0.015	46.43	68.75
15.	0.052	0.025	0.017	32.00	67.31
16.	0.052	0.024	0.016	31.02	66.31

To calculate the degree of desulphurization from treatment with synthetic slag in the pot ($\eta_{S\,zgs}$), we used the relationship:

$$\eta_{S\,zgs} = \frac{Sladle - S_{final}}{S_{ladle}} * 100, \quad [\%] \qquad (1)$$

The total degree of desulphurization treatment with synthetic slag in the pot ($\eta_{S\,total}$) is calculated with:

$$\eta_{S\,total} = \frac{S_{melting} - S_{final}}{S_{melting}} * 100, \quad [\%] \qquad (2)$$

3. RESULTS AND DISCUSSIONS

The data from the experiments were processed in Excel spreadsheets program and the variation degree of desulphurization in the ladle with synthetic slag and the total variation of the degree of desulphurization experimental work loads were obtained (Figure 4).

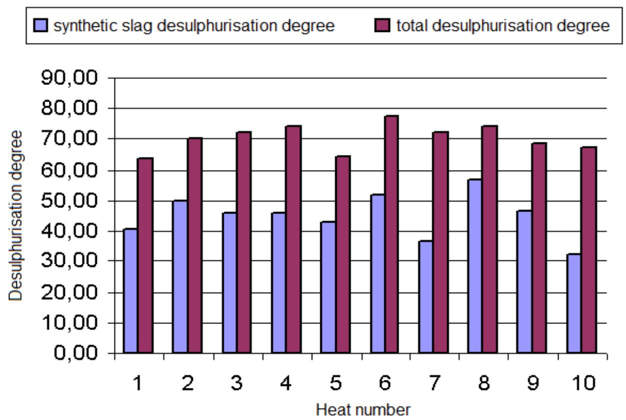

Figure 4. Variation of partial and total degree of desulphurization at steel's treatment with synthetic slag in the pot

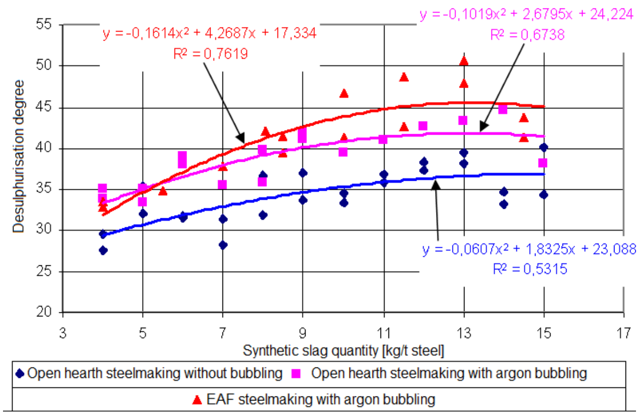

Figure 5. Variation of degree of desulphurization function of the synthetic slag amount

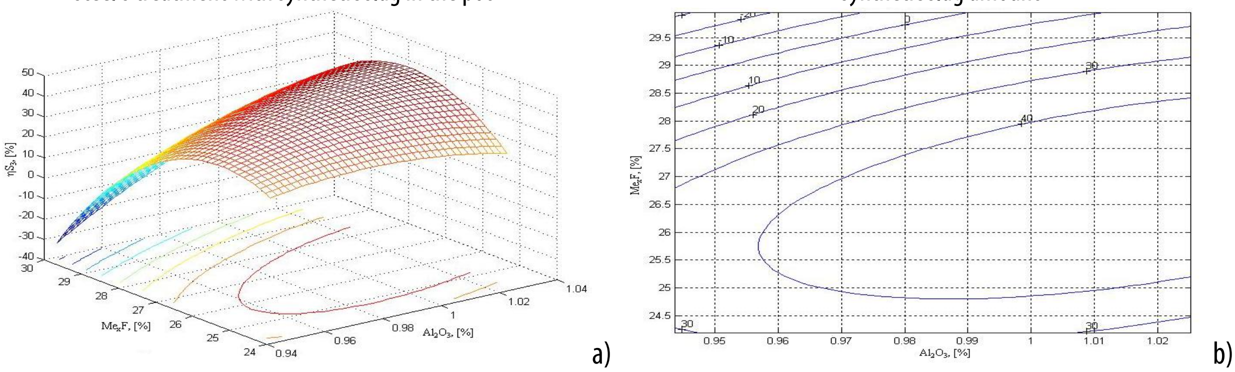

Figure 6. Regression surface (a) and level curves (b) for $\eta S_{2(CaO\ med)} = f(Al_2O_3, Me_xF)$

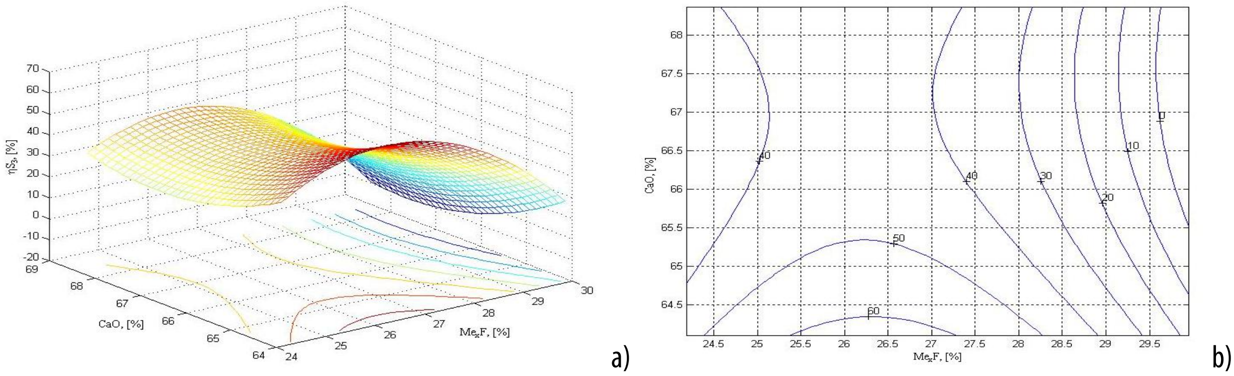

Figure 7. Regression surface (a) and level curves (b) for $\eta S_{2(Al2O3\ med)} = f(Me_xF, CaO)$

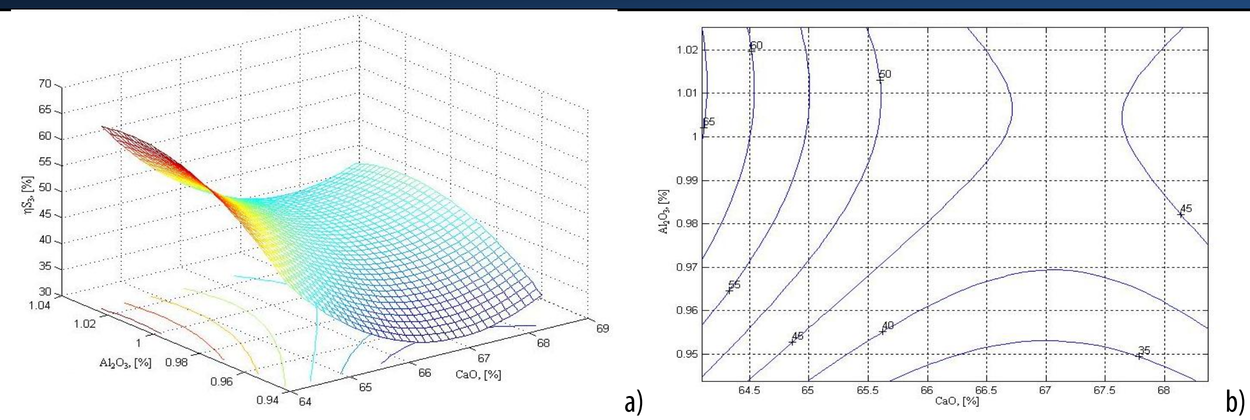

Figure 8. Regression surface (a) and level curves (b) for $\eta S_{2(MexFmed)} = f(CaO)$

From the chart analysis is noted that the degree of desulphurization from synthetic clay pot varied within 30–60% and the total degree of desulphurization varied within 60–80%, resulting in sulfur content at the end of treatment on average of 0,015% S.

The data from MATLAB processing are presented in Figure 5…8. It has been used the following notes for the desulphurization degree: ηS_1 – Electric arc furnace steel made and without steering and ηS_2 – Electric arc furnace steel made and with steering

4. CONCLUSIONS

After studying the process of desulphurization of the steel ladle with synthetic slag obtained by melting desulphurization mixture, the following conclusions arise:

- additions used for deoxidizing the steel will produce a high power slag desulphurization fluoride having an important role, ensuring a good fluidity, an important parameter for the ability of slag deoxidation;
- desulphurization with synthetic slag is effective when used as appropriate slag ternary system $CaO - Al_2O_3 - Me_xF$ and the binary: $CaO - Me_xF$;
- steel with argon bubbling during treatment with synthetic slag will increase the degree of deoxidation / desulphurization by 6% – 10%;
- the amount of slag positively affects the deoxidation degree, so from 4 kg/t to 15 kg/t leads to an increasing degree of desulphurization with 6–9% of steel produced in electric arc furnace (with bubbling with argon in the ladle)
- we established multiple correlations, and in particular, the graphical representation of hyper surfaces regression, of particular interest for practice because they allow determination of chemical composition of the slag areas (areas likely to be achieved in practice), which provides higher values for degree of desulphurization;
- using alumina slag (as a result of aluminum manufacturing technological flow) in synthetic mixture desulphurization slag formation, we ensured economic recovery and we managed to put in circulation a waste deposited in a landfill and play the natural storage space occupied by slag.

Acknowledgement

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