

THE SLAG COMPOSITION INFLUENCE ON THE DEPHOSPHORIZATION AND ON THE LIFETIME OF ELECTRIC ARC FURNACE HEARTH REFRactory LINING

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Abstract

This study analyzes the influence of the slag composition on the extent of EAF hearth refractory wear and especially on the depophosphorization effectiveness (expressed as practical phosphorus distribution between slag and metal Φ_p). The statistical treatment of plant data from 24 campaigns of EAF was conducted. It was found that increase of %CaO, basicity, CaO/FeO ratio and decrease of %FeO are beneficial both for lining protection and phosphorus removal. FeO content must be optimized. Silica, alumina were low and improved the fluidity. Increasing of %MgO affected the wear positively, but Φ_p values negatively. Some negative factors could scatter the results.

Keywords: electric arc furnace, depophosphorization, refractory wear, steel, slag

1 Introduction

Modern EAF steelmaking technology is based on the utilization of basic oxidative slags and basic refractory materials (hearth: MgO or MgO-C) [1].

Repair and replacement of damaged EAF hearth refractory lining represent significant financial investment, downtime and production losses. A lot of various factors participate on the hearth refractory wear process, however in different moments and EAF areas they can act miscellaneous [1, 2, 3]. Slag line is the most critical area within the EAF hearth refractory lining [3, 4]. The slag chemically reacts with lining and dissolves magnesium oxide of the lining till the saturation limit. That's why CaO, MgO-based fluxes are added to the EAF in the beginning of the heat. Calcium oxide is essential for phosphorus removal whilst magnesium oxide is necessary for refractory lining protection [5, 6]. The best case would be an achieving of dual saturation point (saturation of slag both with CaO and MgO), what would satisfy slag foaming requirements as well [5, 7].

Optimization of chemical composition of EAF slag enables refractory wear decreasing and also improvement of slag refining ability. According to the theory high values of phosphorus distribution between slag and metal (i.e. $(P_2O_5)/[P]$) require higher basicities, lower SiO_2 , Al_2O_3 contents, minimal % P_2O_5 and higher amount of iron oxide [6, 8, 9, 10]. However %FeO in the slag must be optimized – very low Φ_p values are documented at too low or too high oxidation potential of the slag (superoxidation). The optimal %FeO is 20-35 wt% [8, 11]. MnO has

negligible effect on dephosphorization process [12]. The influence of MgO is controversial – there are various, sometimes nearly opposite opinions [2, 13]. Beside of chemical composition there are also other important factors facilitating phosphorus removal: lower temperature, larger contact area, longer tap-to-tap time, higher fluidity, bigger slag amount, intensifying agents addition (e.g. Na₂O), etc [8, 14, 15].

The aim of this study was to investigate existing slag system from practice and to define the optimal composition of the EAF slag in order to improve dephosphorization effectiveness and help to protect the EAF refractory lining.

2 Experimental methods

The influence of the most important slag constituents (CaO, MgO, FeO, MnO, SiO₂, Al₂O₃) on the lifetime of EAF hearth refractory lining and on the dephosphorization effectiveness was graphically investigated by using statistical analysis of EAF plant data (metal and slag compositions, refractory wear levels, practical phosphorus distribution i.e. Φp values). There were 24 EAF campaigns evaluated. Refractory wear levels (MgO-C

Table 1 The arrangement of selected parameters according to increasing wear level

Point No.	Refractory wear (cm/heat)	CaO (wt%)	Al ₂ O ₃ (wt%)	SiO ₂ (wt%)	MgO (wt%)	MnO (wt%)	FeO (wt%)	Φp
● 1	0.060	18.43	4.15	12.40	6.19	5.81	44.24	51.87
● 2	0.063	23.91	4.03	12.19	3.38	5.63	39.23	62.67
● 3	0.068	30.05	6.19	12.51	2.40	5.20	32.53	113.62
● 4	0.073	19.86	4.84	13.37	5.25	5.35	42.47	63.88
● 5	0.075	31.40	5.12	14.50	2.70	5.18	30.44	114.77
● 6	0.076	34.40	5.13	14.96	2.68	5.06	27.53	112.53
● 7	0.076	28.87	4.97	13.57	3.12	5.71	32.47	77.90
● 8	0.076	23.11	3.86	12.48	4.50	5.53	40.60	61.00
● 9	0.086	33.27	5.13	13.79	2.21	4.78	29.40	113.56
● 10	0.086	31.09	5.83	12.91	1.86	5.31	30.99	110.25
● 11	0.089	28.37	6.08	13.46	2.17	5.37	33.23	88.31
● 12	0.095	30.11	6.35	13.67	2.03	5.56	31.20	94.92
○ 13	0.103	21.03	3.74	11.23	3.39	5.43	44.59	55.82
○ 14	0.106	20.62	3.21	9.84	2.94	5.23	46.36	52.80
○ 15	0.107	26.72	4.02	12.08	3.20	5.35	36.64	78.39
○ 16	0.109	18.59	4.30	10.63	3.89	5.71	46.15	52.26
○ 17	0.111	25.40	4.02	11.14	2.32	5.21	39.37	59.07
○ 18	0.113	17.45	3.06	9.72	4.31	4.83	50.56	43.50
○ 19	0.117	20.68	3.28	10.98	3.03	5.26	45.96	55.39
○ 20	0.119	24.66	5.12	11.39	4.35	5.08	38.68	65.59
○ 21	0.130	24.68	2.91	9.21	2.39	4.38	43.18	65.05
○ 22	0.130	19.71	3.44	11.00	2.90	5.32	47.23	55.84
○ 23	0.132	19.36	3.11	9.17	2.79	5.48	49.29	60.29
○ 24	0.133	20.18	3.54	10.79	2.74	5.16	45.95	51.26

bricks) were calculated as differences between new and spent bricks and relating it to number of heats (acquired data in cm per heat). The data were arranged to the table according to increasing wear level (see **Table 1**). Wears above 0,1 cm/heat were considered as excessive (12 dark and 12 light marked campaigns). The average values of parameters per campaign were used. The phosphorus distribution parameter Φp was calculated as $\Phi_p = (P_2O_5)/[P]$. Slag and metal were

manually sampled by EAF operator from the slag door area approximately at temperatures ~ 1550 – 1560°C, 7-12 minutes before EAF tapping. The slag samples were analyzed by X-ray spectrometer. Results could be affected by negative factors such as: human factor, sample contamination (consequences of manual sampling), use of oxygen jet before sampling, vicinity of oxy-fuel burner, etc. For most cases the critical wear was indicated in the location under the sill level (consequence of oxygen jet usage).

3 Analysis of the results

3.1 Refractory wear and dephosphorization as functions of the complex slag composition

Owing to better understanding, the data were plotted to the section of the pseudoternary diagram (Fig.1), which illustrates the relationship of basic, acidic oxides and oxides with oxidation potential. Each campaign was marked with point (rising number means higher wear level). Three different zones marked A, B, C were chosen.

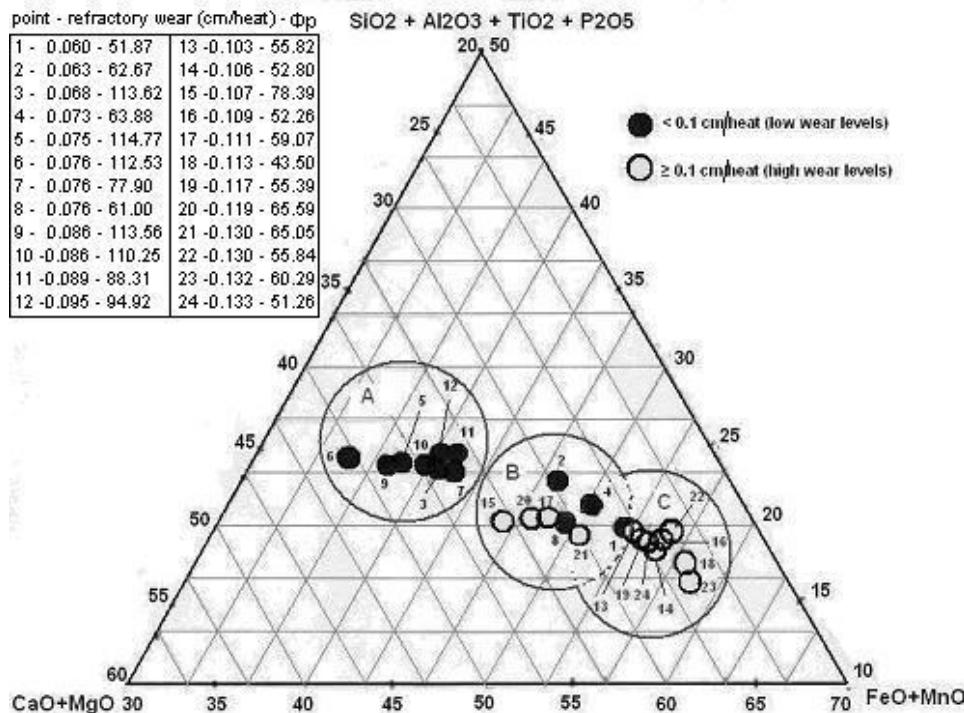


Fig.1 Pseudoternary diagram (CaO + MgO) - (FeO + MnO) - (SiO₂ + Al₂O₃ + TiO₂ + P₂O₅) with plotted wear levels and practical phosphorus distribution values Φ_p .

The campaigns with low wear levels and high Φ_p values (No. 3, 5, 6, 7, 9, 10, 11, 12) were cumulated in the A-marked region (wear ~ 0.082 cm/heat, Φ_p ~ 103,23 on average), whilst the campaigns with high wear levels and low Φ_p values (points No. 13, 14, 16, 18, 19, 22, 23, 24) were clustered in the C-marked region (wear ~ 0.118 cm/heat, Φ_p ~ 53,40 on average). Region marked B represents region in the middle, where both low and high wear levels and Φ_p values were present (wear ~ 0.092 cm/heat, Φ_p ~ 63,44 on average). It's clear that Φ_p values are gradually rising in the direction of % (CaO + MgO) increasing and % (FeO + MnO) decreasing.

Φ_p values in A-region are in comparison to those in C-region nearly double. It's explained by the fact, that despite of a bit higher acidic oxides content (+5,7%), in A-region are the highest basic oxides concentrations and relatively optimal oxidation conditions of the slag (~ 36,4 wt %CaO+MgO, ~ 31,0 wt %FeO on average). EAF refractory wear issue was solved in previous article [3]: It was found that %FeO growth has the worst influence on the lining. Increasing of basicity, CaO, MgO contents has positive effect on the lining life. Silica increases the wear when its content exceeds 14 wt%, alumina accelerates the wear above 5 wt% of Al₂O₃ content in the EAF slag. Paradoxically, the highest wear levels were detected at low SiO₂,Al₂O₃ concentrations.

3.2 Graphical relationships - Φ_p as a function of slag composition

Graphical relationship of phosphorus distribution between slag and metal versus %CaO showed (**Fig.2**) in accordance with theory that rising calcium oxide content significantly intensifies phosphorus removal. However graph of phosphorus distribution versus %MgO content suggests (**Fig.3**, remarkably lower R² coefficient value), that increasing of magnesium oxide content is detrimental. The reason of this fact is the decreasing of the activity of CaO [2].

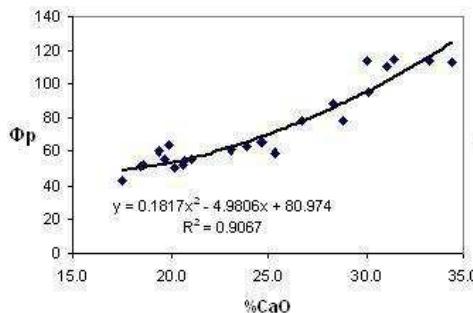


Fig.2 Φ_p as a function of %CaO in the EAF slag

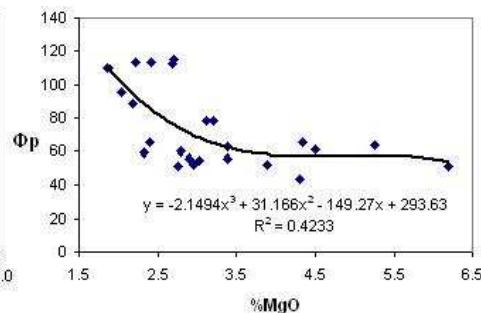


Fig.3 Φ_p as a function of %MgO in the EAF slag.

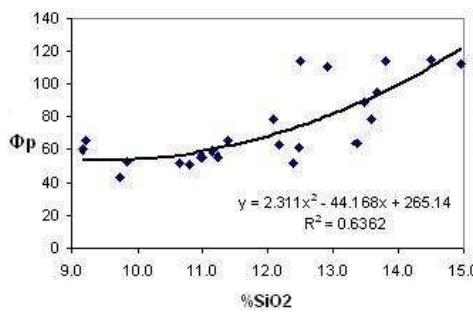


Fig.4 Φ_p as a function of %SiO₂ in the EAF slag

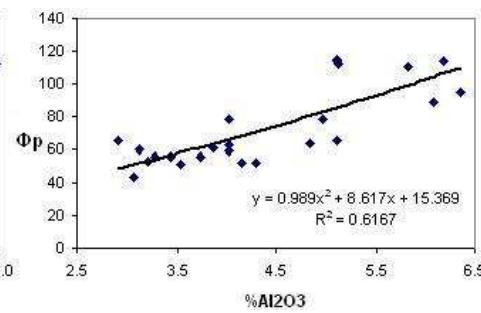
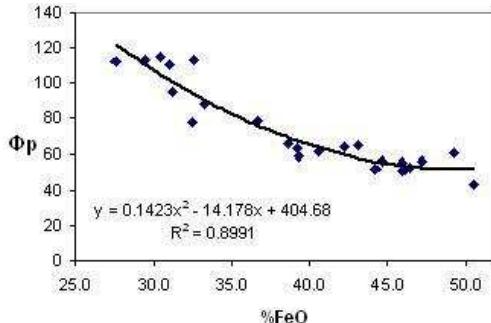
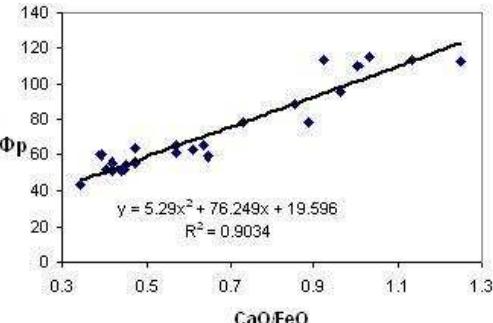


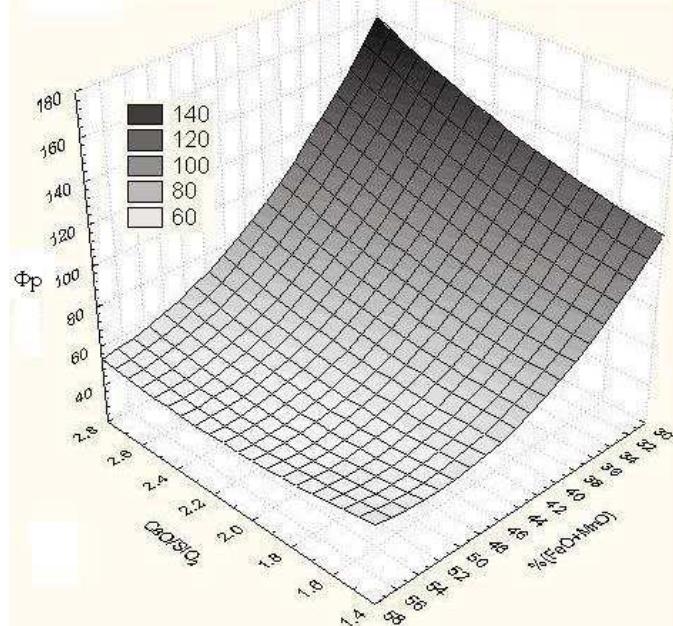
Fig.5 Φ_p as a function of %Al₂O₃ in the EAF slag.

The dependencies of Φ_p versus acidic oxides are illustrated on the **Fig.4**, **Fig.5**. It was supposed that Φ_p will rise both with decreasing %SiO₂, %Al₂O₃ content. The graphs showed improved dephosphorization with increase of %SiO₂, %Al₂O₃. Similar phenomena were observed within the refractory wear [3]. It's explained by the fact that Al₂O₃, SiO₂ levels in EAF slag were sufficiently low and could increase fluidity of the slag. It's well known that Al₂O₃ acts as fluidizing agent in CaO - FeO_x - SiO₂ system. The abrupt increase of slag viscosity in CaO - FeO_x - SiO₂ system is observed above 50 wt % SiO₂ [8, 16, 17].

Fig.6 Φ_p as a function of %FeO₂ in the EAF slagFig.7 Φ_p as a function of %CaO/%FeO ratio.

MnO content in analyzed EAF slags varied only in ~ 4 – 6 wt% range and its effect on the Φ_p values is assumed to be negligible. The dependence of Φ_p versus iron oxide content demonstrated strong negative influence of high %FeO concentrations on the dephosphorization (Fig.6). The same detrimental effect was seen at refractory wear vs. %FeO relationship – see [3]. The lowest average FeO content in the EAF slag was 27,5 wt% and the highest Φ_p values are cumulated in the ~ 27-33 wt%FeO range. The slags high in %FeO are superoxidized. Since both FeO and CaO are necessary for dephosphorization, effect of their own relationship (CaO/FeO ratio) on the Φ_p was studied (Fig.7). This graph clearly proved primary position of CaO in the dephosphorization process.

$$(\text{P2O5})/[\text{P}] = 331.5547 + 18.0069 \times \text{x} - 10.6088 \times \text{y} + 12.1036 \times \text{x} \times \text{y} - 1.2586 \times \text{x}^2 \times \text{y} + 0.1179 \times \text{y}^2$$

Fig.8 Φ_p as a function of basicity B_2 and oxidation potential of EAF slag.

Finally, the three-dimensional quadratic graph of phosphorus distribution as a function of binary basicity ($B_2 = \text{CaO}/\text{SiO}_2$) and oxidation potential of the slag was considered (Fig.8). There's a

clear change of Φ_p values within % (FeO+MnO) decline. High Φ_p values are concentrated at lower % (FeO+MnO), whereas maximal Φ_p values are present in high basicity area. The EAF technology should be managed in the way: ~ 30 wt% FeO and $B_2 \sim 2,8$.

4 Conclusions

Presented article deals about effect of EAF slag composition on the refractory wear and dephosphorization effectiveness. The plant data from 24 EAF campaigns were statistically treated. The illustration of studied campaigns in pseudoternary diagram as well as graphical relationships showed negativity of high FeO content on both wear and dephosphorization processes. Opposite effect had increasing of %CaO, basicity. Silica and alumina improved fluidity and so the phosphorus removal (their content in the EAF slag was low). %MgO acts positively on the lining, but negatively on the Φ_p . Thus it's very important for EAF technology to manage the %FeO content (optimum ~ 27-33 wt%), acquire the high basicity and optimize the MgO content. The content of acidic oxides should be in the level which doesn't deteriorate the fluidity of the slag. It's important to mention the possible negative factors that could scatter the obtained results: manual sampling, sample contamination, oxygen jet using, vicinity of oxy-fuel burner, etc., but almost within all the graphs (with exception of $\Phi_p = f(\%MgO)$ function) high values of R^2 coefficient were acquired (i.e. R^2 above ~ 0,6).

References

- [1] P. Raschman: Acta metallurgica slovaca, Vol.6, 2000, p. 69-76 (in Slovak).
- [2] K.C. Mills, Y. Su, A.B. Fox, Z. Li, R.P. Thackray, H.T. Tsai: ISIJ International, Vol. 45, 2005, No.5, p. 619-633.
- [3] T. Borovský, J. Kijac, M. Domovec: Acta Metallurgica Slovaca, Vol. 15, 2009, No. 2, p.77-85.
- [4] Z. Li, K. Mukai, Z. Tao: ISIJ International, Vol. 40, 2000, Suplement, p. S101-S105.
- [5] E. Pretorius, R.C. Carlisle: Iron & Steelmaker, Vol. 26, 1999, No.10, p. 79-88.
- [6] T. Borovský: Optimization of the lime amount added in the dephosphorization period of the steel, Metalurgia Junior'09 Conference, Košice, 2009, ISBN 978-80-553-0250-8 (in Slovak).
- [7] M. Novák, J. Bulín, M. Přibyl, R. Heide, J. Straka: The experience with foamy slag technology introduction in production of clean and superclean steels at conditions of Pilsen Steel Steelmill, 22nd state conference with foreign participation, Rožnov pod Radhoštěm, Tanger, 2008, p. 216-226 (in Czech).
- [8] G. Li, T. Hamano, F. Tsukihashi: ISIJ International, Vol.45, 2005, No.1, p.12-18.
- [9] H. Ishii, R.J. Fruehan: Iron & Steelmaker, Vol. 24, 1997, No. 2, p. 47-54.
- [10] E.T. Turkdogan: ISIJ International, Vol. 40, 2000, No. 9, p. 827-832.
- [11] R.J. Fruehan, C.P. Manning: Final Report, AISI/DOE Technology roadmap program, American Iron and Steel Institute, Pittsburgh, 2001.
- [12] A.T. Morales, R.J. Fruehan: Metallurgical And Materials Transactions B, Vol. 28, 1997, No.6, p. 1111-1118.
- [13] Z. Adolf, P. Suchánek, T. Gumulec, R. Sikora: The oxidic flux influence on the steel dephosphorization process, 22nd state conference with foreign participation, Rožnov pod Radhoštěm, Tanger, 2006, p. 68-74 (in Czech).

- [14] M. Swinnerton: The influence of slag evolution on BOF dephosphorisation, Thesis, University of Wollongong, New South Wales, Australia, 2005.
- [15] J.J. Pak, R.J. Fruehan: Metallurgical transactions B, Vol. 22, 1991, Issue 1, p. 39-46.
- [16] M. Nakamoto, J. Lee, T. Tanaka: ISIJ Int., Vol. 45, 2005, No.5, p. 651-656.
- [17] T. Hamano, M. Horibe, K. Ito: ISIJ Int., Vol.44, 2004, No.2, p. 263-267.