

## PHOSPHOROUS BEHAVIOR IN ELECTRIC ARC FURNACE STEELMAKING WITH THE MELTING OF HIGH PHOSPHOROUS CONTENT DIRECT REDUCED IRON

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The world products of direct reduced iron are presented not only by metalized pellets (DRI) and hot briquetted iron (HBI) with low phosphorus content, but also by these products with high phosphorus concentrations, depending upon the quality of iron ore and its degree of enrichment. They may contain up to 0.08% of phosphorus and above it[1]. This makes it necessary to analyze the process of dephosphorization during the melting and refining processes of these products as a charge material in the electric arc furnace steel making.

A real steelmaking process involves many complex physical and chemical coupled phenomena such as oxidation, decarburization, dephosphorization, and slag formation. Lowering of phosphorus content in steel is a critical requirement for steels used in thin sheets, deep drawn applications and all applications requiring high uniform deformability. Phosphorus is also known to make the steel prone to embrittlement during heat treatment and cause degradation of electrical properties. [2, 3]

Commercially-produced hot briquetted iron (HBI) contains considerably more phosphorus than scrap. This raises the question of how much dephosphorisation can be achieved when using direct reduced iron in an electric arc furnace (EAF). A commonly held misconception amongst EAF operators who do not currently use HBI, is that the relatively high level of phosphorus in HBI will make dephosphorisation difficult, if not impossible [4].

M Meraikib has been studied the phosphorous behavior in steelmaking with melting direct reduced iron which having average content of phosphorous 0.01wt% in DRI, he investigated mainly the effect of increasing the sponge iron proportion in the metallic charge on the phosphorous content of steel.

He has found the reverse relationship between the direct reduced iron wt% in the charge and the phosphorous content of the steel. [5]

Fruehan et al investigated the Behavior of Phosphorus in DRI/HBI during electric furnace Steelmaking, they observed that DRI/HBI products have low contents of copper, nickel, nitrogen, sulfur, and they can contain large amounts of phosphorus. Depending upon the quality of ore used to produce the DRI/HBI; these products can contain five to ten times as much phosphorus as scrap. Most commercially available DRI/HBI materials commonly contain between 0.03 to 0.09% phosphorus as compared with 0.015 to 0.02 % for scrap. DRI/HBI produced from lower grades of ore can contain as high as 0.15%P. [6,7,8]

**Table 1** Chemical composition of the sponge iron used at EZZ Flat Steel, %

Metallization	Fe <sub>Total</sub>	Fe meT	C	P	S	CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>
92.61	91.24	84.5	1.67	0.061	0.0026	1.9	1.0	2.9	0.35	0.10

**Table 2** Chemical analysis of scrap used at EZZ Flat Steel, %

C	Si	Mn	S	P	As	Cu	Sn	Cr	Nb	Ni	Al	Co	Fe
0.25	0.37	0.5	0.04	0.037	0.01	0.3	0.01	0.071	0.006	0.12	0.04	0.004	98.23

**Table 3** Assay of lime used at EZZ Flat Steel, %

MgO	SiO <sub>2</sub>	P	S	CaO
6.5	3.5	0.1	0.08	90.32

**Table 4** Slag chemical composition after the melting of the two baskets (sample 1), after continuous feeding of sponge iron (sample 2),%

№ плавки	проба	CaO	SiO <sub>2</sub>	FeO	MgO	Al <sub>2</sub> O <sub>3</sub>	MnO	Cr <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>
1	1	32.56	15.28	35.33	6.16	6.46	1.94	0.68	0.897	0.659
	2	31.14	12.35	43.15	5.21	5.36	1.14	0.42	0.729	0.483
2	1	26.99	11.73	47.46	5.50	5.62	1.14	0.38	0.691	0.481
	2	23.84	11.37	49.79	7.05	5.18	1.27	0.44	0.581	0.458
3	1	27.61	12.22	46.48	4.24	5.88	1.84	0.56	0.668	0.469
	2	25.37	11.90	50.55	3.75	5.63	1.32	0.41	0.589	0.443

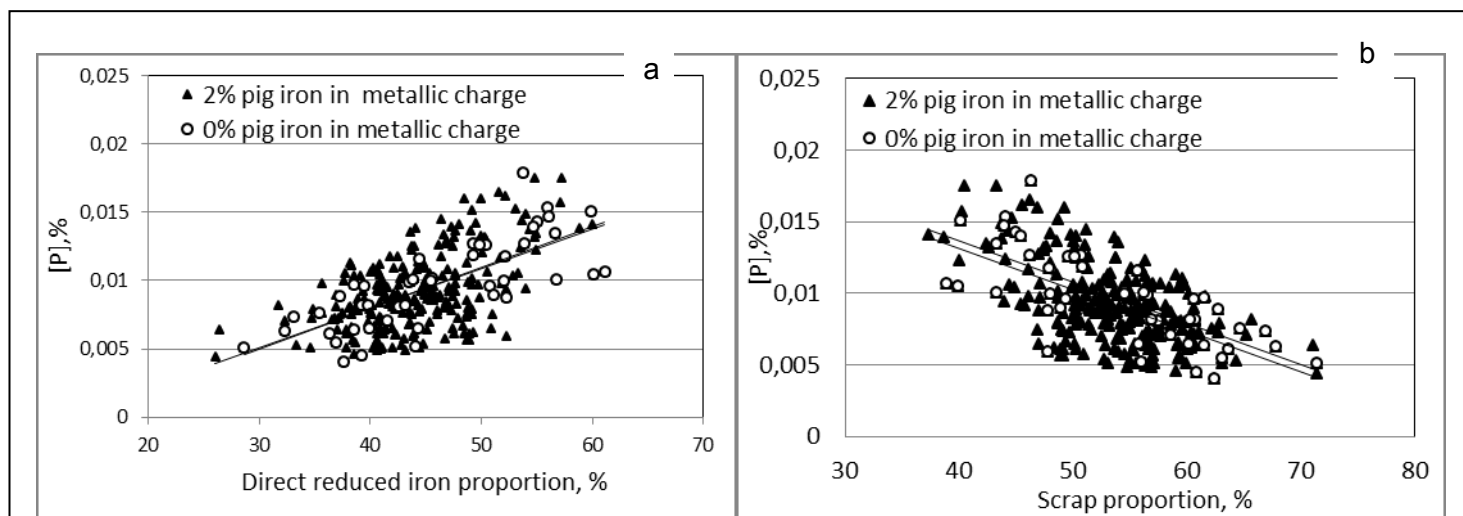
This research will discuss the phosphorous behavior in the molten metal with direct reduced iron melting which having phosphorous content 0.061wt %, and the factors associated with the production processes in the electric arc furnace 220 tons at EZZ Flat Steel in Egypt.

The EAF Metallic charge consists of DRI and HBI having a degree of metallization 92.61 % and scrap. The proportion of metallized materials in the charges varied from 25 to 60 % Wt.

The furnace is charged with a two buckets and continuous feeding, the bucket no. 1 containing scrap, direct reduced iron (DRI+HBI), coke and fluxes it have about 100 ton (80 t scrap+20 t DRI) weight in average, then the power switched on and charge converted to molten pool, after 10 minutes power on time, the second bucket charging, this bucket weighting about 60 ton (45 t scrap+15 t DRI). Immediately after this charge is complete melting; DRI and burnt lime are continuously feeding, the amount of this stage depend on the summation of the previous buckets ranging from 30 to 100 ton DRI. Therefore, when DRI started to melt, the temperature was measured and pair of samples were taken, from the slag and metal.

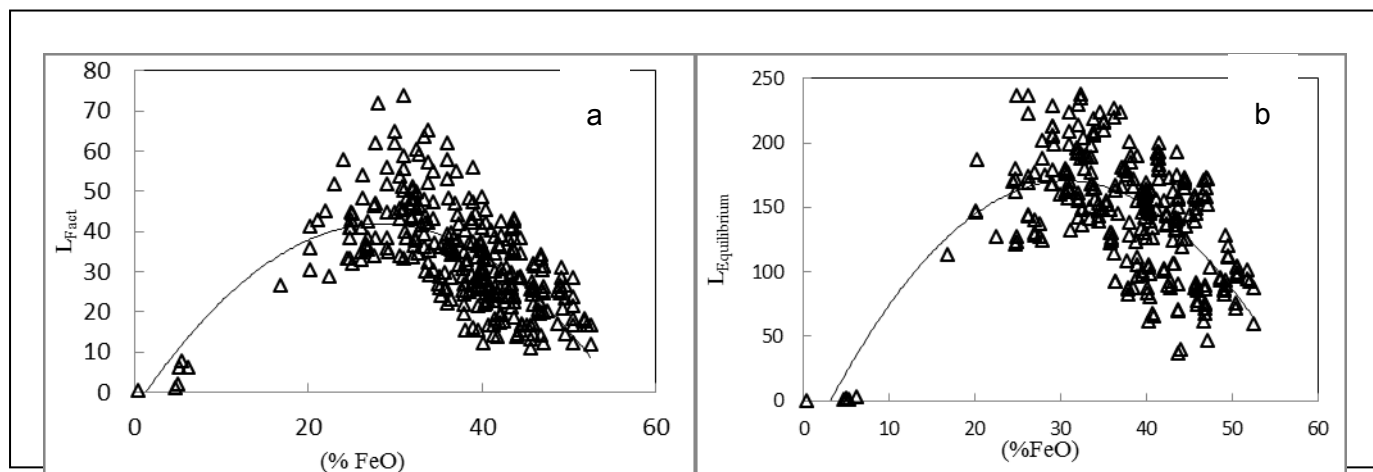
**Table 5** Temperature and metal composition analysis after the melting of the two baskets (sample 1), after continuous feeding of sponge iron (sample 2),%

No. Heats	Sample	C	Mn	S	P	Cu	Ni	Cr	Sn	Si	T °C
1	1	0.055	0.019	0.04	0.01	0.206	0.067	0.037	0.0104	0.005	1535
	2	0.049	0.010	0.037	0.012	0.191	0.062	0.0259	0.0095	0.005	1620
2	1	0.049	0.019	0.026	0.012	0.378	0.057	0.013	0.001	0.001	1617
	2	0.042	0.008	0.016	0.013	0.256	0.042	0.005	0.0065	0.001	1645
3	1	0.067	0.016	0.027	0.009	0.183	0.073	0.023	0.0085	0.005	1527
	2	0.042	0.0076	0.023	0.014	0.146	0.058	0.015	0.0067	0.005	1623



**Fig.1** Variation of the phosphorous content of hot metal with the direct reduced iron proportion (a); the scrap proportion (b) in the charge

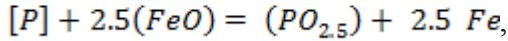
Figure 1 shows the variation of the phosphorous content of metal with the direct reduced iron proportions (a) and the scrap proportion (b) in the charge of EAF-220. Direct reduced iron charged in electric arc furnace 220 ton consists of HBI and metallized pellets. The figure shows that with the increasing of direct reduced iron ratio in the metallic charge from 26 to 67% leads to an increase in the phosphorous concentration from 0.005 to 0.015% in the molten metal. It is also seen that the addition of the pig iron to 2 % (5 ton) containing 4 %C and 0.4% P, has no a great effect on the phosphorus content in the metal.



**Fig. 2** The fact (a) and equilibrium phosphorous distribution ratio(b) in dependence of the FeO content in the slag

Figures 2 show the dependence of the fact and equilibrium phosphorus distribution ratio between the slag and metal with the iron oxide (FeO) content in the slag in EAF-220. The influence of FeO concentration on the Phosphorus partition ratio in a temperature range from 1620 to 1665oC, basicity value from 1.4 to 3.4 and a wide range of FeO % in the slag has been studied, the results show that the increase of FeO concentration in the slag initially enhances both the fact and equilibrium Phosphorus partition ratio but the trend is reversed beyond a certain level of (FeO), the FeO concentration corresponding to this transition varies with basicity but remains within the overall range of 25-30%. [9,10]

The values of the phosphorus equilibrium distribution ratio was calculated based on an assessment of the activity of phosphorus oxides in the slag in the theory of regular ionic solution model (V.A.Kozheurova) [11]. According to the following equations,



$$\lg K = \lg \frac{x_{PO_{2.5}} \cdot \gamma_{PO_{2.5}}}{x_{FeO}^{2.5} \cdot \gamma_{FeO}^{2.5} \cdot [P] \cdot f_P} = \frac{1120}{T} - 1.385$$

hence  $x_{PO_{2.5}}, x_{FeO}, \gamma_{PO_{2.5}}, \gamma_{FeO}$  – The ionic fraction of the cation and activity coefficient of the oxides in the slag;

$[P]$  and  $f_P$ - concentration and activity coefficient of the phosphorous in the metal.

$$x_{PO_{2.5}} = \frac{(\%P)}{31 \sum n},$$

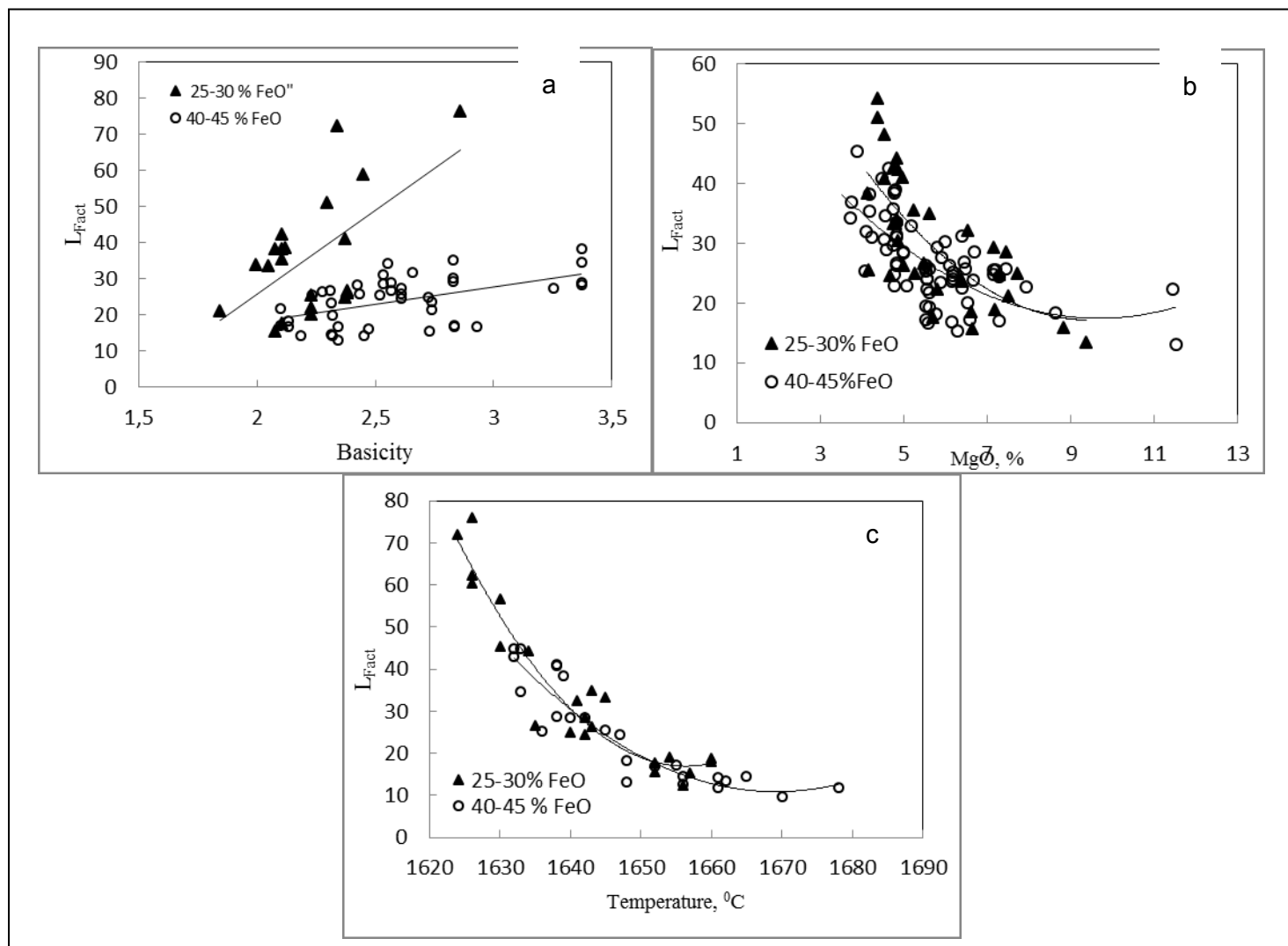
$\Sigma n$ - summations of moles fractions of slag components for 100 gm.  $L_P = \frac{(\%P)}{[\%P]} = \frac{31 K f_P x_{FeO}^{2.5} \gamma_{FeO}^{2.5} \sum n}{\gamma_{PO_{2.5}}}$

$$\lg \gamma_{FeO} \approx \lg \gamma_{Fe} = \frac{1000}{T} [2.18 x_{Mn} x_{Si} + 5.9(x_{Ca} + x_{Mg})x_{Si} + 10.5 x_{Ca} x_P];$$

$$\lg \gamma_{PO_{2.5}} \approx \lg \gamma_{(P)} = \lg \gamma_{Fe} - \frac{10500}{T} x_{Ca};$$

$x_{Fe}, x_{Mn}, x_{Ca}, x_{Mg}, x_{Si}, x_P$  –ionic fraction of cations in the slag.

Figure 2.a , 2.b show the optimum FeO content in the slag, it should be about 30%. With this (FeO) concentration the maximum observed distribution ratio between the slag and metal is obtained. This applies to both the observed and the equilibrium data. A comparison between figures 2a and 2b illustrate that the fact distribution ratio of phosphorus is very different from the equilibrium values, it means that the reach to the equilibrium state is difficult.



**Fig. 3** Variation of the fact phosphorous distribution ratio with slag basicity(a); MgO content in slag % (b); and temperature of molten metal before tapping (c)

Figure 3.a, illustrates that at high concentration of iron oxides in the slag from 40 to 45% the slag basicity have a weak effect on the observed phosphorous partition ratio, at the same time, with moderate FeO content in the slag from 25 to 30%, the slag basicity have significant effect on the distribution ratio, the maximum  $L_{Fact} = 50 \dots 75$  obtained at basicity  $B = CaO/SiO_2 \approx 2.5 \dots 3.0$ .

Figure 3.b shows the dependence of the observed phosphorous partition ratio  $L_{Fact}$  on the magnesium oxide (MgO) content in the slag. It can be seen that with increasing concentration of MgO in the slag the value of  $L_{Fact}$  decreased, at 4% MgO  $L_{Fact} = 40 \dots 60$ , and at 10%  $L_{Fact} = 10 \dots 20$ . Clearly, for a more complete dephosphorization with the melting of direct reduced iron with high phosphorous content, is advisable to have a minimum MgO content of the slag-about 4%. At the same time it is necessary to take care of the stability of EAF refractories, which generally decreases with decreasing content of MgO in the slag.[12]

From Figure 3.c it can be seen that the observed distribution ratio of phosphorus between slag and molten metal  $L_{Fact}$  strongly dependent on temperature. At 1625 °C  $L_{Fact} = 60 \dots 75$ , with increasing temperature up to

1660 °C  $L_{\text{Fact}}$  value is reduced to 10 ... 20 and then there is a little change of  $L_{\text{Fact}}$  with increasing temperature. That is, for maximizing the dephosphorization process it is necessary to have the lowest possible temperature at which achieves the high rate of metallized materials melting, and the minimum costs associated with further secondary treatment steel. In this case it is possible to recommend to have a temperature of metal before tapping in a range between 1635 ... 1625 °C.

## CONCLUSIONS

The effect of melting direct reduced iron (DRI and HBI) with high phosphorous content 0.061% on dephosphorization process in an EAF charge have been investigated. The experiments have been conducted at EZZ Flat Steel Company in Egypt, with annual production capacity 1.2 mln. t of hot-rolled flat steel with thickness 1.0–12.0 mm. This analysis showed that, the dephosphorization reactions are sufficiently far from equilibrium. For efficient dephosphorization with using the metallized materials, which have phosphorus content 0.061%, the slag should have 25–30% FeO, 4% MgO, and the slag basicity preferably should be between 2.5 and 3.0, while its temperature — 1625–1635 °C.

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