Features of low-voltage potential effect on metallic phase in slag formed in course of out-of-furnace iron treatment by granulated magnesium

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Abstract
The paper presents laboratory data on reduction of metal losses in form of metal drops with slag as a result of the effects of electrical influence of low power density at operations out of furnace treatment of iron with granulated magnesium supplied through an immersion lance.
Keywords: OUT-OF-FURNACE TREATMENT OF IRON, GRANULATED MAGNESIUM, SLAG, METAL DROPS, LOW-VOLTAGE ELECTRICAL POTENTIAL

The works on development of scientific and technical bases and study of extension possibility of the list of technological options of use of low-voltage potentials overlay method [1], in particular at a stage of out-of-furnace treatment of cast iron, are performed in Institute of Ferrous Metallurgy of NAS of Ukraine.

As a result of carrying out a complex of theoretical, analytical and technological researches on laboratory installation when treatment iron with powder materials under the conditions of superimposing of low-voltage potentials on tuyere and metal melt, the increase in a level of desulfuration of metal and reduction of temperature losses during processing were noticed [2].

The **objective** of this research was the investigation of impact of low-voltage potential on metal phase in the molten slag formed in course of out-of-furnace treatment of iron by the granulated magnesium.

Research technique. In laboratory site HMI, experiments on molten iron processing with granulated magnesium (MGP-99 with fraction 0.35×10-3 ÷ ÷ 1.45 ×10-3 m) in neutral gas flow in a ladle of capacity of 100 kg) have been conducted; the ladle is lined with chamotte refractory including application of method of superimposing of low-voltage potentials. The method presupposes activation of refining processes at out-of-furnace treatment of iron with gas-powder streams by supplying of low-voltage potential to the blowing-off module and electrode from a source of direct current.

Experiments were conducted by two techniques: 1) when using only the granulated magnesium; 2) with additional additive of powder lime in the ladle.

Carrying out of pair experiments on the similar composition metal melted in the induction furnace and divided into two approximately equal portions was the basic rule of conducted experiments. In course of experiments, comparable expendable parameters on intensity of magnesium input and quantity of lime additive (in case if it is used) were maintained. One of experiments was conducted with supplying of low-voltage potential to tuyere and immersed contact graphite electrode (option 1), and the second was comparative without electric impact (option 2).

In course of experiments, the synthetic iron obtained by melting of pig-iron waste in the induction furnace IP-100, which was heated to the temperature 1500-1520ºC, was used. The ladle lining was heated before experiments carrying out.

Before blowing and after its completion, the initial and final samples of metal and slag were taken from a ladle by steel spoon for the subsequent chemical or spectral analysis. After crushing of covering slag, a metal phase (beads) was extracted from it; this metal phase was divided into fractions by their sizes, and the chemical analysis was conducted.

In Table 1, the averaged data on the number of metal beads within slag phase are provided before and after treatment by granulated magnesium. As the analysis shows, early (furnace) slag contains about 10-17% of metal phase in the form of small beads. The slag formed after blowing by magnesium in a flow of neutral gas is saturated with metal phase up to 46.2% and 56.4% in case of use of electric potentials and without electric affect respectively.

Table 1. The initial and final slag parameters averaged for series of melting when iron treatment by granulated magnesium

No	Prototype versions	Sample weight, kg	Slag weight, kg	Beads weight, kg	Beads quantity, %
Experiments without lime additive in a ladle					
1	Early slag	0,0834	0,0750	0,0084	10,0
2	Slag of option 1	0,0752	0,0391	0,0344	46,2
3	Slag of option 2	0,0848	0,0368	0,0483	56,4
Experiments with lime additive in a ladle					
1	Early slag	0,0700	0,0580	0,0120	17,1
2	Slag of option 1	0,1650	0,1300	0,0300	18,8
3	Slag of option 2	0,1250	0,0900	0,0350	28,0

From the table, it is seen that due to use of electric potentials, the quantity of beads in slag is reduced in comparison with results of experiments without electric impact (for 9.2 and 10.2% when using lime additive and blown with granulated magnesium only respectively); and the lime additive in ladle on melt surface causes significant decrease in beads quantity in final slag despite higher content of beads in early (furnace) slag. In this case, in the option with use of electric potentials in comparison with early (furnace) slag, the number of beads has been increased only by 1.7%, and without electric impacts by 10,9%.

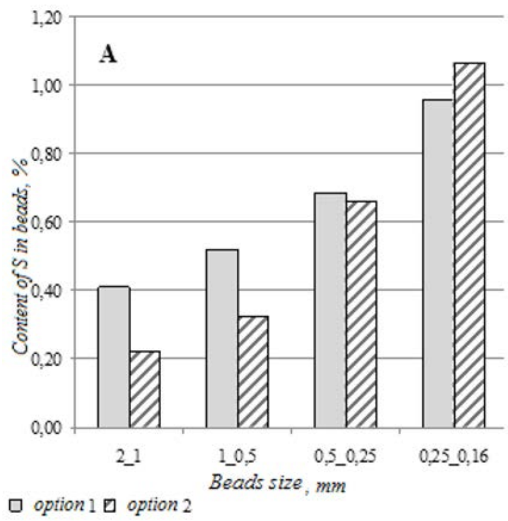
The established fact of significant decrease in beads quantity during correction of chemical composition of covering slag can probably be explained by the mechanism presented in papers [3-4], i.e. it emerges due to increase in surface forces in the slag border and metal drops which prevents penetration of the last ones into slag. In options with use of electric potentials, in this case, the certain role is played by additional warming of slag melt from passing of current that reduces viscosity of slag cover; moreover, the directional transport of metal drops in electric field, as shown in paper, is possible [5].

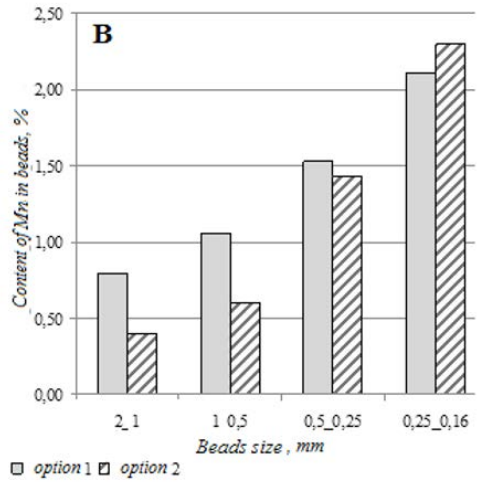
The analysis of fractional composition of metal beads (Table 2) indicates one possible mechanism electric potentials impact on decrease in level of slag saturation by metal phase: creation of conditions for small beads conjunction into larger fraction which precipitates from slag melt into metal faster. So, it is established that in option with use of electric potential, the quantity of beads of fraction $(1\div2)\times10^{-3}$ m increases, and the quantity of fraction $(0.16\div0.25)\times10^{-3}$ decreases.

Table 2. The fractional structure of metal beads in a slag phase averaged by prototype versions

No	Prototype versions	Beads quantity in a slag phase on fractions, %				
		0.16-0.25 10^{-3} m	0.25-0.50 10^{-3} m	0.50-1.0 10^{-3} m	1.0-2.0 10^{-3} m	Over 2.0 10^{-3} м
1	Option 1	19,6	20,7	17,5	35,1	7,1
2	Option 2	23,8	20,8	17,4	30,0	8,0

The chemical analysis of beads of various fractions has shown that the content of sulfur and manganese in the bead depends on its size: the smaller bead is, the higher content of sulfur and manganese will be (Figure 1) that corresponds to results of researchers' papers [6]. However, it should be noted that when metal treatment with use of low-voltage potential, the level of evaluated components maintenance was much higher than in option without electric impact but only in large beads $(05\times10^{-3}\div2{,}0\times10^{-3}$ m), and in small beads $(0{,}16\times10^{-3}\div0{,}5\times10^{-3}$ m) their content was lower. Level of sulfur content in beads of the smallest fraction (less than 0.16×10^{-3}m) in case of its extrapolation on the micro sizes was close to the content of sulfur in slag phase for the specific option. It indicates the possibility of formation of small fraction of beads as a result of chemical interaction of slag with oxides, and consequently, partial transition of metal matrix from large beads into slag via formation of iron oxides. At the same time, electric impact probably intensifies the process of iron oxidation from beads; it is testified by decrease in quantity of the smallest fraction of beads.





options: 1 – with electric impact, 2 – without impact

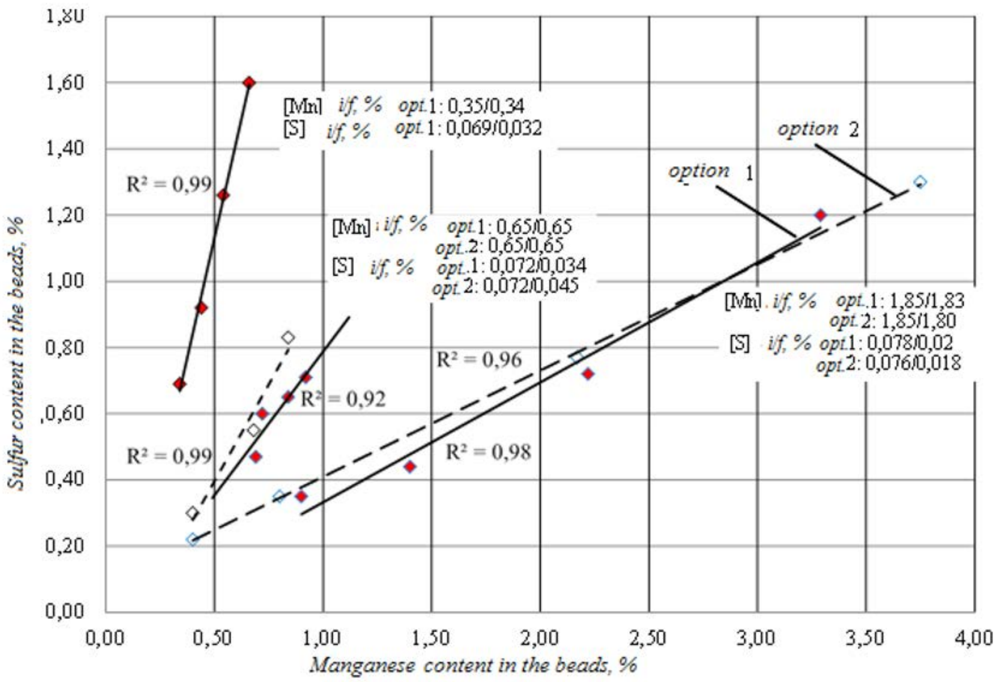
Figure 1. Averaged indicators of content of sulfur (A) and manganese (B) in beads depending on fractional structure

It has been established that the content of sulfur in beads of fraction $0.16\times10\text{-}3\div0.25\times10^{-3}$ m in melts without impact increases by 8.0 – 10.0 times in comparison with its content in the final metal, while in melts with electric impact this increase is 15-18 times, which is significantly higher. At that, the content of manganese in beads increases by 1.4 – 1.7 times only. It can be explained by the fact that sulfur, first of all, is surface active element, and its concentration in surface layer is higher than in metal melt.

In course of consideration of the mechanism of beads formation, it is possible to emphasize two stages: 1) in case of iron treatment operation, magnesium when in melt forms gas-vapor bubbles of the size $2\times10^{-3}\div10\times10^{-3}$ m, on which surface the sulfur is adsorbed, 2) when emerging bubbles, the gas cavity is opened and the internal surface enriched with sulfur is collapsed with formation of metal drops (beads) of size $1.5\times10^{-3}\div3.0\times10^{-3}$ m. The size of a drop is closely connected with the size of the para-gas bubble of magnesium preceding its emergence. So, for beads of an average size 2×10^{-3} m, the steam-gas bubble should have the sizes $8\times10^{-3}\div10\times10^{-3}$ m. Metal drop getting into slag melt begins to interact with it; therefore, its size is reduced due to the process of "dissolution" of matrix mentioned above – bead iron. Thus, the content of sulfur in beads is determined by process of metal drop formation and by subsequent change of its size: the smaller is bead, the higher is the content of residual sulfur in it.

As concerns manganese, change of level of its content in the bead during dispergation of metal is determined by its volume distribution in melt. Therefore, at separation of metal drop (bead), the level of manganese content in it is not changed substantially in comparison with the initial content of manganese in the main metal that can be noticed in the analysis of dependences presented in Figure 2.

Additional increase in sulfur and manganese content in large beads ($1\times10^{-3}\div2\times10^{-3}$ m) in case of impact of low-voltage potential is probably determined by influence of potential on simultaneous transfer of these elements from metal volume to the melt, which fragments form metal beads as a consequence. High extent of connection between the content of manganese and sulfur in beads is also confirmed by high coefficients of correlation (R^2: 0.92 – 0.99) of dependences (Figure 2). It can demonstrate that these beads components are in the interconnected generalized complexes; therefore, these elements can move in parallel. Such effect was already noticed earlier in the analysis of change of manganese and sulfur content in metal in course of converter process [7].



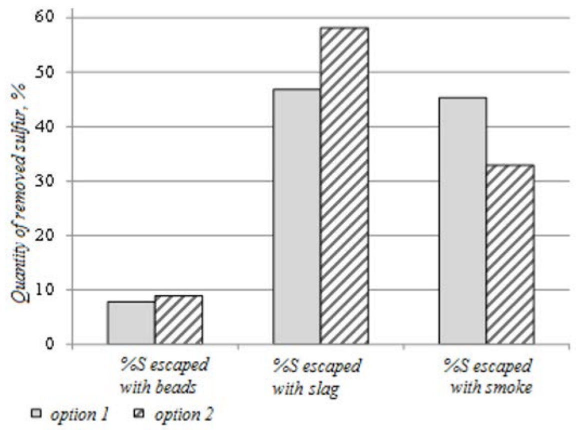
options: 1 – with electric impact, 2 – without impact

Figure. 2. Dependence of sulfur content on the manganese content in beads divided into fractions, in case of various initial contents of manganese in metal (in the figure also there are: initial - "i" and final – "f" levels of content of manganese [Mn] and sulfur [S] in metal)

As it can be seen from the analysis of dependences presented in Figure 3, there is a concrete ratio between amount of atoms of sulfur and manganese depending on the initial content of manganese in iron in the whole range of beads sizes under investigation.

So, in case of the content of manganese in iron 0.35 –1.85%, the ratio of amount of sulfur atoms to amount of manganese atoms was changed from 3 to 0.3 in such a way that at low content of manganese in iron (at the level of 0,35%mass), each atom of manganese can keep three÷atoms of sulfur according to stoichiometry; and visa verse, at higher content of manganese (at the level of 1.85%mass) only one atom of sulfur can keep three atoms of manganese. Therefore, within each selected chemical composition of iron, beads with specified chemical composition are formed, and the ratio of sulfur and manganese is maintained at the certain level determined by the initial content of manganese independently of the sizes of metal beads formed in slag.

In course of analysis of distribution of removed sulfur between three phases (metal of beams, slag and gas phase (see Figure 3)), it has been established that in case of option without impact (option 2) the sulfur removed from the base melt passes to slag melt to a greater extent and is accumulated in beads to a lesser extent that is corresponded to data of other researchers [8]. In option with impact by electric potentials (option 1), the increase in sulfur quantity has been noticed; that can be result of its anodic burning. In this option less sulfur is fixed as a part of bead that demonstrates decrease in a possible resulfuration of base metal at return of part of beads due to electric impact.



options: 1 – with electric impact, 2 – without impact

Figure 3. Distribution of removed sulfur between beads, slag and gas phase

Conclusion

Thus, the laboratory researches in HMI on evaluation of application of method of imposing of low-voltage potential on system blow-off tuyere – liquid metal melt when iron treatment by granulated magnesium in the stream of neutral gas have shown positive influence of electric impacts on noticeable decrease in unavoidable losses of iron at its out-of-furnace treatment in the form of mixed up metal beads in slag, and also decrease in level of possible resulfuration of iron at return of beads to metal.

It is revealed that the content of sulfur in beads is determined by process of formation of metal drop and its subsequent size: the less size of bead is, the higher content of sulfur will be.

Also it has been revealed that the contents of sulfur and manganese in beads when iron treatment by magnesium are closely interconnected.

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