REDUCTION OF SILICON IN BLAST FURNACE

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Abstract

Nowadays it is claimed that the silicon appears in the metal not only from the slag SiO_2 reduction at the liquid phase, but also from a gaseous SiO. Presented in this paper, laboratory tests were aimed on finding the effect of temperature and MgO containing in the slag on the dynamics of the Si transition to the hot metal at the liquid phase at the time when slag lies on metal. Observations of industrial units in combination with laboratory tests allowed to approximately determine the contribution of silicon from the gaseous SiO to Si containing in hot metal. As a result, developed guidelines and proposals for the conduct of blast furnace technology to minimize Si in hot metal.

Keywords: blast furnace, silicon, silicon oxide and dioxide reduction

1. INTRODUCTION

Current views on the chemical composition of hot metal are as follows [1]:

- Si content should be minimized up to a value of 0.2 %,
- Mn content can be minimized, even to below 0.2 %.

The resulting silicon content in hot metal is mainly driven by production program, the possibilities of blast furnace process and the technical and technological features of production in the steelworks. Minimization of silicon in hot metal is important for technology but mainly for economy because of:

- the lowering of fuel consumption in the blast furnace,
- shortening of steel melting,
- reduction of lime consumption, and thus the production of slag in the steelwork.

These aspects result in a reduction of steel production cost without quality sacrificing. It is a sufficient reason for the use of Si minimizing technology. The ultimate silicon containing in the tap hot metal is the cause of [1 - 9]:

- reduction of SiO_2 to Si from the primary liquid slag above the raceway zone,
- reduction of SiO which originates from coke combustion (SiO_2 ash coke) at high temperature,
- reduction SiO_2 from slag which is in contact with metal during period between taps,
- reduction SiO_2 of coke ash which is submerged in slag and hot metal.

Silicon transition to metal at liquid phase's during SiO_2 reduction by coke carbon or carbon dissolved in the metal proceeds according to reactions:

$$(SiO_2) + 2C_{coke} = [Si] + 2\{CO\} \tag{1}$$

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

The thermodynamic of these reactions has included the authors studied [4-9]. While Elliot, Gleiser and Ramakrishna [2] state that the conditions for the reduction of silica contained in the coke as well as the adoption of silicon by iron are especially beneficial at high temperature on the layers of tuyeres and bosh. The high temperature favors the formation of gaseous SiO, whereas carbon-saturated iron, with low Si activity, immediately dissolves formed silicon. According to the authors [1, 3, 9], a large part of silicon goes to the hot metal from a gaseous SiO, which is derived from two sources:

from the slag flowing down through the coke by reaction:

$$(SiO_2)_{slag} + C_{coke} = \{SiO\} + \{CO\} \qquad (3)$$

from the molten in the raceway coke ash by reaction:

$$(SiO_2)_{ash} + C_{coke} = \{SiO\} + \{CO\} \qquad (4)$$

The total amount of produced gaseous SiO largely determines the amount of SiO resultant silica contained in ash coke. This process, as well as the rate of absorption of Si to iron is significant due to prevailing here the highest temperature located directly above the raceways. As the authors conclude [7-9], uncontrolled growth of the coke ash content may increase the silicon content in hot metal. Thus, the amount of silicon in the metal depends on the amount of the Si produced by the reaction:

$$\{SiO\} + C_{coke} = [Si] + \{CO\} \qquad (5)$$

The SiO volume and rate of absorption of silicon from SiO is growing with increasing temperature. The authors [5, 9] claimed that the temperature in the combustion and dripping zones (the area between the bottom surface of the cohesive zone and the outer surface of the dead man) causes an increase silicon content in hot metal.

Thus, the silicon content in hot metal is mainly determined by the transformations of silica present in the coke. With this is directly associated the cohesive zone height - the higher zone causes the higher Si content in hot metal. Due to the impact of the cohesive zone position on the silicon content in hot metal, according to the authors [6 - 9], it is necessary to predict the expected changes in the location of the zone depending on the type of burden materials. Authors [7 - 9] assumed that lowering of the melting temperature (increase of cohesive zone) favors the presence of SiO_2 in materials, which in an environment of partially reduced oxides of FeO and MnO creates fusible ferrous and manganese silicates. Generalizing, ore materials with small amount of silica, characterized by higher temperatures of melting, favor the lowering of cohesive zone in blast furnace and consequently reduce the silicon content in hot metal.

It is estimated that the Si content in the metal, coming from other sources than the hearth slag, reaches values from 0.1 % to 0.4 % [3, 7, 9]. The higher the heat supplied to the heart, the more Si content in the metal. However, it is still possible to regulate content Si in hot metal, preventing excessive growth of SiO_2 reduction from liquid slag in hearth, by changing the chemical composition of the slag, temperature and reaction time. Taking this into account, the objective of this study is fragmentary determination of the influence of time, temperature and slag MgO content on the final content of Si in the metal at constant temperature.

2. RESEARCH METHODS AND RESULTS

Laboratory tests conducted in the laboratory at AGH University on devices such as described in detail [7 - 9]. Metal used in the study obtained by carbonizing the iron up to saturation, adopting the values, given by J. Chipman [5]. The masses of metal and slag were 0.025 kg each.

Slag used for research was produced by the synthesis of chemically pure oxides in the liquid phase at temperature about 1873 K in the cryptol furnace. The chemical composition of tested slag shows **Table 1**. The examinations were conducted at temperatures of 1723 K, 1773 K and 1823 K in the time from 0 to 320 minutes. The results are presented at **Fig. 1**.

Statistical analysis of Si changes in Si (ΔSi) as a function of time (t), temperature (T) and mass % MgO content in slag allowed to estimate empirical equation:

$$Y = \Delta Si = f(t, MgO, T) \quad (6)$$

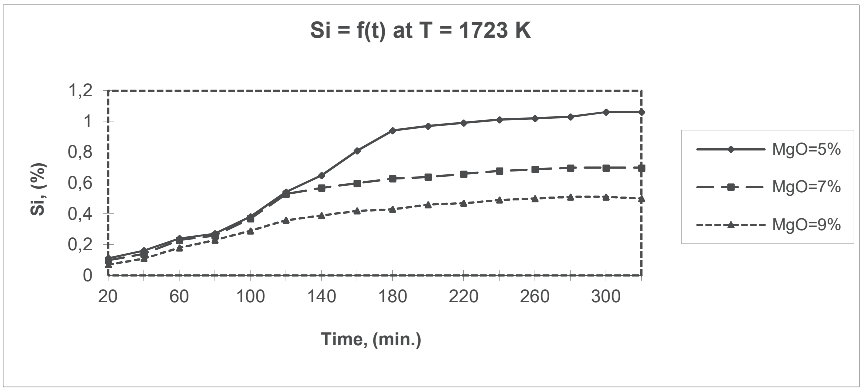
$$Y = -4.4763 * 10^{-4} * t - 6.689 * 10^{-3} * MgO + 1.1135 * 10^{-3} * T - 1.784 \quad (7)$$

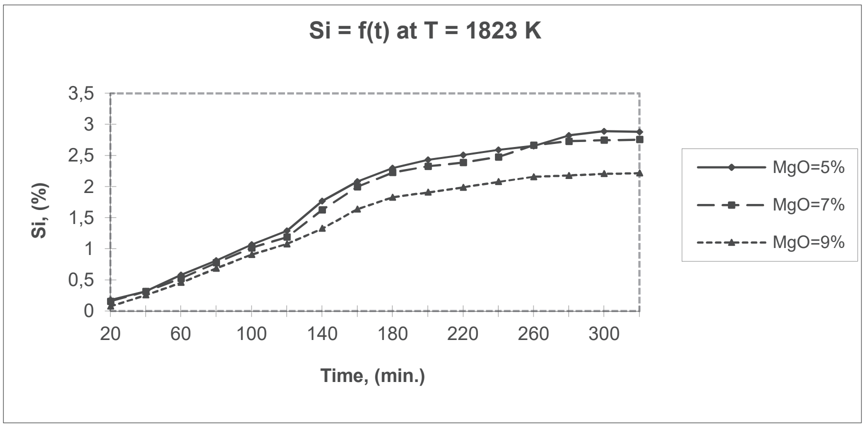
at R = 0.71 from 147 observations and significance α = 0.01.

Table 1 Chemical composition of tested slag

No.	CaO	MgO	SiO_2	Al_2O_3	$\frac{CaO}{SiO_2}$	$\frac{(CaO + MgO)}{SiO_2}$	$\frac{(CaO + MgO)}{(SiO_2 + Al_2O_3)}$
1	44,03	9,01	40,02	7,02	1,112	1,325	1,128
2	45,09	7,04	40,90	6,98	1,102	1,274	1,089
3	45,51	5,15	41,60	7,10	1,095	1,218	1,040

It means, that on this basis it is likely to predict and simulate conditions (for metal's temperature, time of reaction and % MgO in the slag), which are necessary to obtain a change of silicon content in relation to the taped Si, derived from SiO_2. This means that it is possible to influence on change of Si content in hot metal in advance.





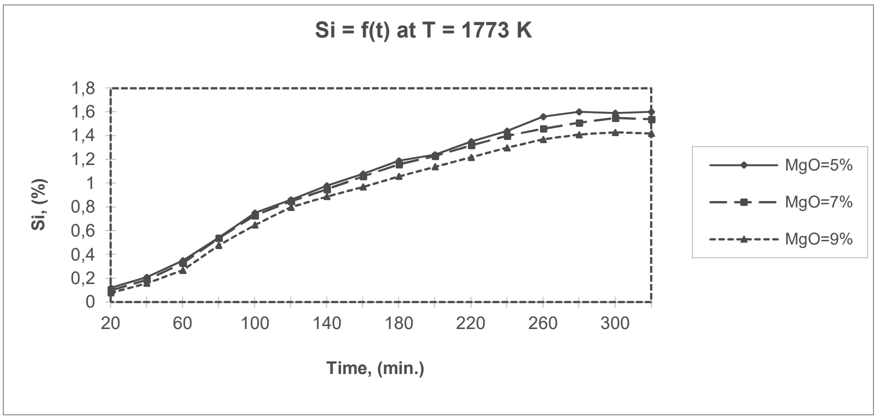


Fig. 1 The results of slag SiO_2 reduction by carbon-saturated metal at 1723 K, 1773 K, 1823 K, at a time from 20 to 320 minutes, at different contents of MgO in the slag

3. ANALYSIS OF RESULTS AT TECHNOLOGICAL ASPECT

There were carried out an observation of blast furnaces operation at ArcelorMittal Departments in Krakow and in Dabrowa Gornicza in case of determine average periods between taps. (at the time when slag lies on the metal) and average contain of Si at temperatures of research and slag compositions similar to used in laboratory. So at this time has been achieved in ArcelorMittal Department in Krakow:

- at T = 1723 K about 0.27 % Si at MgO = 5 %
  0.26 % Si at MgO = 7 %
  0.23 % Si at MgO = 9 %
- at T = 1773 K about 0.54 % Si at MgO = 5 %
  0.54 % Si at MgO = 7 %
  0.48 % Si at MgO = 9 %
- at T = 1823 K about 0.81 % Si at MgO = 5 %
  0.78 % Si at MgO = 7 %
  0.69 % Si at MgO = 9 %

Since the Krakow Department ArcelorMittal hot metal temperature is less than 1773 K, and the average ranges of Si content is about 0.78 % - 0.85 %, this means that about 0.25 % to 0.4 % Si in hot metal comes from reduction of gaseous SiO. For ArcelorMittal Department Dabrowa Gornicza:

- at T = 1723 K about 0.24 % Si at MgO = 5 %
  0.23% Si at MgO = 7 %
  0.18% Si at MgO = 9 %

- at T = 1773 K about 0.35 % Si at MgO = 7%
  0.33% Si at MgO = 8 %
  0.27% Si at MgO = 9 %

- at T = 1823 K about 0.58 % Si at MgO = 5 %
  0.53% Si at MgO = 7 %
  0.46% Si at MgO = 9 %

Since the Dabrowa Gornicza Department ArcelorMittal hot metal temperature is about 1773 K, and the average ranges of Si content is about 0.55 % - 0.65 % at 7 % MgO, this means that from gaseous SiO reduces to metal about 0.2 to 0.3 % Si.

CONCLUSIONS

Laboratory tests and technological, statistical analysis let to draw the following conclusions:

- Silicon is reduced from slag SiO_2 by carbon, dissolved in iron and goes to metal at little amount if:
  - reaction temperature (between slag and metal) is lower,
  - MgO content in slag is about 9 %,
  - reaction time (and therefore in the blast furnace the period between the tap) is low - about 40 - 60 minutes.
- The content of Si in the metal after mentioned examination period at constant temperature is less than in the BF hot metal of 0.15 % - 0.35 %. This means that in apart from the silicon reduction reaction from the slag, another source of silicon in hot metal is the reduction of gaseous SiO.
- The statistical analysis made to obtain an empirical function of changes of the Si content in metal (such as hot metal), on which it is possible to predict and simulate changes of Si content in the metal, derived solely from the slag SiO_2 reduction reaction by carbon dissolved in the metal.
- Effect of slag MgO on Si content in the metal is lower at high temperatures. Thus, in order to obtain the Si content in hot metal within the limits of 0.30 % to 0.40 % (as required by modern basic oxygen furnace plant) the following is necessary (mainly at ArcelorMittal in Krakow):
  - to increase the content of MgO in the slag up to 9 %,
  - to shorten the reaction time (lying the slag on the metal), to maximum 40 minutes, what is possible,

- do not exceed temperatures of hot metal above 1500^0C,
- Scientific data indicates that the increase of the slag basicity CaO/SiO_2 from 1.1 (research and industrial practice) to 1.2 with MgO and Al_2O_3 content in slag about 9 %, can reduce the Si content of approximately 0.15 % - 0.2 %, which is very desirable and may be tested in the coming years in industry at ArcelorMittal Department Krakow.

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