The study of magnesium oxide influence on thermophysical and electric properties of ferrosilicon manganese slag

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ABSTRACT

The studies on determination of thermophysical and electric properties of ferrosilicon manganese slag established that magnesium oxide addition in its composition contributes to the viscosity reduction in homogeneous region by 10%, viscous flow activation energy up to 61.4 kJ/mol. This allows improving process parameters of ferrosilicon manganese production owing to the intensification of reduction processes and improvement of interphase interaction on slag, reducing agent and metal interfaces.

INTRODUCTION

Manganese reduction from slag and its final composition to a large extent depend on the temperature in the furnace, which is determined by the charge and slag melting temperature. The papers [1, 2] demonstrated that raise in ferromanganese melting process temperature by 200 K reduces the manganese equilibrium concentration in slag sevenfold and increases the silicon content in the melt. As such, the study of magnesium oxide influence on ferrosilicon manganese slag melting temperature is attractive.

1. STUDIES

The experiments were carried out with high-temperature microscope that provides the automatic temperature recording. The semi-synthetic slag produced by magnesium oxide addition in the industrial slag of marketable ferrosilicon manganese manufacture was used as study object (slag (1), Table)

Table 1. Influence of MgO content on slag melting temperature

Slag No.	Chemical composition, % wt					
	MnO	SiO_2	CaO	MgO	Al_2O_3	T_{liq}, K
1	17.3	50.8	12.1	4 5	8.4	1485
2	17.1	48.6	13.0	8.8	7.9	1568
3	14.8	47.9	11.8	11.6	7.8	1590
4	13 3	43.6	11.2	169	7.6	1614
5	12.9	39 8	10.6	22.8	7 2	1626
6	17.2	42.8	18.8	4.8	7.7	1541

The use of semi-synthetic slag provided obtaining the samples, which did not differ from real slag in terms of additions. Statistical processing of the obtained results was carried out by 120 test measurements of semi-synthetic slag melting temperature. After that, the groups of slag with magnesium oxide concentration close to the value indicated in the table were distinguished. In such a case, the total of slag components remained more or less unchanged and giving due consideration to Fe_20_3 (0.5-0.8%), R_20 (3.5-4.5%), S (0.8-1.2%) was 98-99%. The slag samples were placed on molybdenum base and heated with constant rate of 20 K/min. The changes in sample shape were observed with optical system. The temperature, at which the sample is shaped into the drop, was considered to be equal to the liquidus temperature T_{liq}. The accuracy of its determination was ± *5* K.

2. RESULT

The obtained results (see Table) demonstrate that magnesium oxide influences dramatically on melting temperature of the slag being studied. It was established that it is 1483 K for initial slag (I) containing 4.5% of MgO and 1626 K for slag (5) containing 22.8% of MgO, i.e. by 141 K more. The analytic dependence between magnesium oxide in ferrosilicon manganese slag and its melting temperature (K) was obtained using mathematical processing of test data:

$T_{liq} = [(\%MgO)/600.15(\%MgO) + 329.45] \times 10^6$; R = 0.99

High correlation coefficient (R) value demonstrates statistical confidence of the obtained dependency. The slag (6) with high CaO content has also higher melting temperature (1541 K) as compared to the initial slag.

The quantitative influence of magnesium and calcium oxides additions on slag melting temperature can be assessed using concentration gradients. Comparison of temperature concentration gradients values for MgO (T_{liq}/MgO %) and CaO (T_{liq}/CaO %) shows that at addition of magnesium oxide in slag composition this parameter equals to 10.4 K/MgO %, whereas the same CaO quantity leads to the gradient reduction up to 8.8 K/CaO %. As can be seen from the above, the results of conducted studies allow making important conclusion for practical purposes that CaO replacement with MgO in ferrosilicon manganese production slag increases its melting temperature and, consequently, ferrosilicon manganese melting process temperature.

During the electro-thermal process, substantial quantity of heat for oxides reduction is generated by the current passing through the liquid phase and depends on its electrical conductivity, which has a great influence on electric mode of melt process. A series of papers was dedicated to the studies of molten slag electrical conductivity; however, influence of magnesium oxide on its changes in the acid slag has been studied insufficiently that results in the necessity for additional studies.

The slag 1-5 (see Table) was used as study object. The experiment was carried out by AC bridge method, in the zero diagonal of which the indicator F = 510 providing for bridge sensitivity of at least $0.66*10^{-5}$%/mm was included.

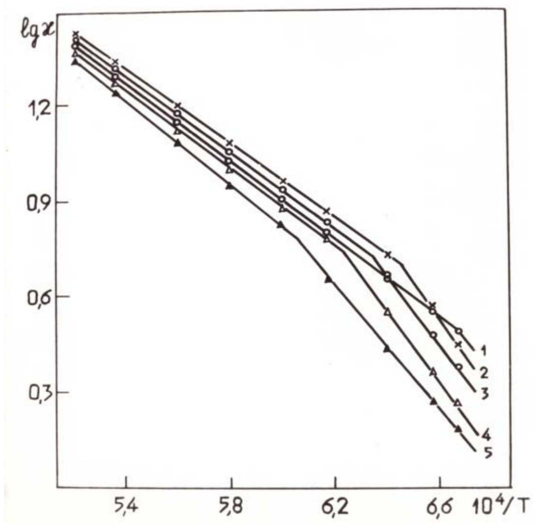

Fig. 1. Relation between electric conductivity logarithm (H) of ferrosilicon manganese slag and reciprocal temperature, when MgO content, % wt, is as follows: 1 - 4.5; 2 - 8.8; 3 - 11.6; 4 - 16.9; 5 - 22.8.

It was found that increase in MgO content in the temperature range being studied (1523-1823 K) results in ambivalent changes in the slag electrical conductivity. Thus, with MgO increase up to 22.8% and MnO decrease, it is reduced by 19.85 as compared to the base slag. This is especially noticeable below the temperature of 1630 K that equals to the slag melting temperature and its transition temperature in the heterogeneous region, as evidenced by line 5 bend (Fig. 1). At high temperature region, the electric conductivity of all slag increases, whereas simultaneous decrease of MnO content in it (slag (4), (5)) results in the electric conductivity reduction by 1.0-1.7% as compared to the initial slag (1).

Viscosity is an important characteristic of metallurgical molten slag. Its value has a significant effect on temperature distribution, movement of charging materials in the ferroalloy furnace (charge descent), kinetics of reduction processes, value of metal and slag losses and other process factors [2].

The studies on slag viscosity *h* were carried out using vibration method based on the change determination of rod forced oscillations during its immersion in the viscous medium. The obtained results are presented in Fig. 2. The viscosity values at 1723-1823 K, which correspond to the slag temperature at ferrosilicon manganese tapping at the industrial electric furnaces, are of particular interest. Thus, at 1773 K the viscosity of slag (5) containing 22.8% is 0.36 pas with temperature increase.

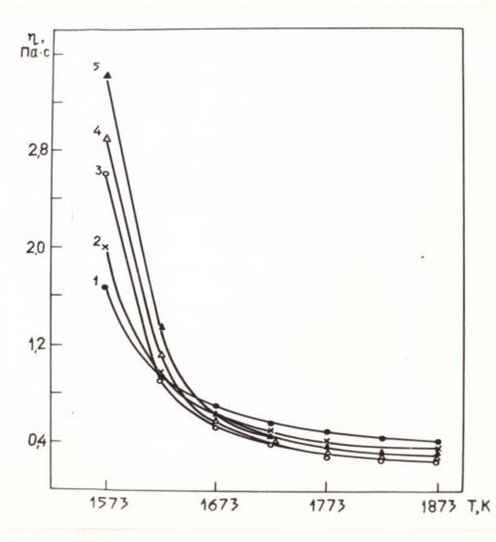

Fig. 2 Dependence of magnesia slag viscosity (pas) on temperature (T), when MgO content, % wt, is as follows: 1 - 4.5; 2 - 8.8; 3 - 11.6; 4 - 16.9; 5 - 22.8.

The viscosity of slag (5) is reduced by about 10% up to 1823 K. Further increase in the temperature is slightly influences on its viscosity; however, it has lower value than slag (1) viscosity. The prominent feature of ferrosilicon manganese slag with high MgO content is a sharp increase in its viscosity at the temperature below 1673 K, which denotes at narrow temperature range of its crystallization. The activation energy of viscous flow $E_п$ for the slag being studied was calculated according to the known equation:

$$\eta = A \times e^{En/(RT)}$$

where, η is slag viscosity; A is pre-exponential factor; R is Boltzmann constant; T is temperature.

The processing of test data in the coordinates ***Lgη-f(1/T)*** was carried out using the following equation:

$$Lg\eta = A + B/T,$$

based on which the activation energy of slag viscous flow in the homogeneous region is determined. The activation energy of initial slag (1) is 106.7 kJ/mol, whereas at the increase in magnesium oxide concentration up to 16.9%, the activation energy reduces and is 91.4 kJ/mol. However, when MgO content (slag (5)) is 22.8%, the increase of E_{fl} up to 219 kJ/mol is observed, as can be explained by presence of relatively high-melting compounds of Mg_2SiO_4 (T_{liq} = 2163 K). Consequently, MgO content in the ferrosilicon manganese slag exceeding 16.9% is undesirable.

As can be seen from the above, MgO addition in the ferrosilicon manganese slag contributes to the viscosity reduction in the homogeneous region by 10% and its temperature increase by 140 K more. In such a case, slag electrical conductivity remains more or less unchanged (it is reduced by about 1.5-2.0%). The improvement of slag physical characteristics contributes to the intensification of manganese and silicon co-reduction processes, as well as enhances slag and metallic phase separation conditions.

SUMMARY

As a result of studies, the quantitative influence of magnesium and calcium oxides additions on slag melting temperature concentration gradients was established. An important conclusion for practical purposes was made that CaO replacement with MgO in ferrosilicon manganese production slag increases its melting temperature and, consequently, temperature conditions of simultaneous processes, manganese and silicon co-reduction in the alloy. The results of laboratory test were proved under industrial conditions during melting of ferrosilicon manganese using magnesia slag in the furnace of 75 MVA. In such a case, owing to the process temperature increase by 80-120 K, the electric furnace capacity was increased by 2.8-3.0% and specific consumption of manganese raw materials and electric power was decreased by 37.8 kg/t and 49.6 kWh/t, respectively.

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